DEVELOPMENT OF ATTACHMENTS FOR FOUR-WHEEL RIDING TYPE RICE TRANSPLANTER

by

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Development of attachments for four wheel riding type rice transplanter"** is a *bonafide* record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Athul Chandran K.

Dedicated to

My Family & Profession

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SYMBOLS AND ABBREVIATIONS

mha	:	million hectare
mT	:	million tonnes
et al.	:	and others
cm	:	centimetre
kg	:	kilogram
Rs.	:	Rupees
h	:	hour
/	:	per
ha h^{-1}	:	hectare per hour
IRRI	:	International Rice Research Institute
APAU	:	Andra Pradesh Agriculture University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
Zn	:	Zinc
Fe	:	Iron
Mn	:	Manganese
B	:	Boron
Cu	:	Copper
Mo	:	Molybdenum
Cl	:	Chlorine
Si	:	Silicon
ha	:	hectare
h ha^{-1}	:	hour per hectare
kg ha^{-1}	:	kilogram per hectare
ml	:	millilitre
rad	:	radian
ml min^{-1}	:	millilitre per minute
kg cm^{-2}	:	kilogram per square centimetre
km	:	kilometre
km h^{-1}	:	kilometre per hour

rpm	:	Revolutions per minute
PTO	:	power takeoff
psi	:	Pounds per square inch
Mpa	:	Megapascal
μm	:	micro metre
ppm	:	parts per million
IMD	:	Indian Meteorological Department
AEU	:	Agro-Ecological Units
mm	:	millimetre
%	:	per cent
AFC	:	Actual field capacity
TFC	:	Theoretical field capacity
E_f	:	Field efficiency
HOC	:	Hourly operation cost
HFC	:	Hourly fixed cost
AWH	:	Annual working hours
HVC	:	Hourly variable cost
UAOC	:	Unit area operating cost
m	:	metre
°	:	degree
DC	:	direct current
g	:	gram
kPa	:	Kilopascal
dpi	:	dots per inch
min	:	minute
l	:	litre
$l\ min^{-1}$	:	litre per minute
$ml\ l^{-1}$	:	millilitre per litre
$l\ ha^{-1}$	:	litre per hectare
AOH	:	Annual operating cost
CAD	:	Computer-aided design

V	Volt
PVC	Poly vinyl Chloride
$m^2\ min^{-1}$	square metre per minute
$l\ m^{-2}$	litre per square metre
KAU	Kerala Agriculture University
CFMTTI	Central Farm Machinery Training & Testing Institute

Introduction

CHAPTER I

INTRODUCTION

Rice is the most important cereal food crop of the world providing major source of the food energy for more than half of the human population. Rice is currently grown in over a hundred countries across the world on an area about 150 million hectares with annual production of over 525 million tonnes, constituting nearly 11 percent of the world's cultivated land (Rai, 2006). More than 90 per cent of the world's rice is produced and consumed in Asia where it is an integral part of culture and tradition. In India, rice is presently grown in an area of 43.42 mha with a production of about 98.95 mT (Anon., 2014). At the current rate of population growth, the country has to produce about 120 mT of rice by 2030 to feed the ever growing population (Anon., 2011).

In 2014-15, the paddy production in Kerala was 5,62,092 Tonnes from an area of 1,98,159 ha (Anon., 2017). Palakkad district is the key producer contributing 42.18 per cent of the total rice production. There are three major rice-growing seasons in Kerala. The '*Virippu*' (First crop) season starts in April-May and continues up to September-October, '*Mundakan*' (Second crop) season starts in September-October and extends up to December-January, where as the '*Puncha*' (Third crop) season starts in December-January and extends up to March-April.

Paddy is grown traditionally by manual transplanting. Manual transplanting is labour intensive, involving drudgery and is one major factor for increased production cost. Manual transplanting takes about 250-300 man hours ha^{-1} which is roughly about 25 per cent of the total labour requirement of the crop (Singh *et al.*, 1985). Paucity of labourers is an important problem in Kerala. Hence the less expensive, farmer friendly and labour saving method of mechanical transplanting of paddy is the option, as it ensures timely transplanting and attains optimum plant density that contributes to high productivity.

A rice transplanter is a mechanical device to serve the purpose of planting rice seedlings onto a puddled paddy field. Although rice is grown in areas other

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than Asia, rice transplanters are used mainly in East, Southeast, and South Asia. This is because rice can also be grown without transplanting.

Different types of rice transplanters are being used and the four wheel riding type machine is getting popular as it can ensure speedy operation so as to meet the challenges imposed by climate change. The machines are costly and the price for different makes range from Rs. 1 to 1.8 million. The economic feasibility of an agricultural machine depends on the annual hours of use. Apart from the advantages, the annual hours of use of the four wheeled machine can be very low, so that the high capital investment may not be justified. Hence an agro-economic analysis of the machine is highly relevant to evolve mechanisation strategies.

Presently, the machines available in the market are provided with lugged rubber wheels for operation in puddled field. These wheels can get easily damaged if used on firm ground for transit from one field to another. This necessitates hiring of transport vehicles, resulting in escalation in the cost of use. Hence the development of a suitable transport wheel for the four wheeled transplanters is required.

Further, application of bio fungicides like *pseudomonas fluorescence*, application of pre-emergent herbicides at the time of transplanting, foliar application of plant health promoting agents like bio-agents and micro nutrients etc. are emerging strategies to improve the economics of rice cultivation. There is a good scope for providing applicator attachments to the transplanting machine.

Considering the above, increasing the annual machine usage for minimising the hourly operational cost of four wheeled rice transplanters and to improve the economics and climate resilience of rice cultivation has much relevance in the present scenario. Combining the operations of plant protection and nutrient application with transplanting will be a boon to the Indian farmer as it can minimise the cost of operation. In India, only a few studies have been done so far in development of attachments for rice transplanters. Hence, the development of attachments for a four wheeled riding type transplanter was contemplated with the following specific objectives:

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1. To conduct an agro-economic analysis of a four wheeled riding type rice transplanter.
2. To develop transport wheels for four wheeled rice transplanter.
3. To develop an applicator system for four wheeled riding type rice transplanter for spraying of liquid bio-fungicides and micronutrient mixtures.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

In this chapter, a brief review of research works carried out in the development of attachments for four wheel riding type rice transplanter and the methods adopted for its evaluation are presented.

2.1 RICE TRANSPLANTING

Rice is grown either by direct seedling i.e. broadcasting, drilling, sowing or transplanting. Among these methods transplanting is a suitable and economic method in high rainfall areas. In this method, seedlings are raised in the seedbed for 20 to 40 days before they are uprooted and transplanted on the well puddled main field flooded with water. This method certainly requires more labour input and cost than the broadcasting method.

Devasundrarajah (1971) found out that the two major advantages of transplanting are: (i) The transplanted crop occupies in the field for shorter period of time compared to the direct wet seeded crop. (ii) It facilitates the control of weeds. Hence, the method of transplanting is widely used in regions where the water can be controlled and there is no shortage of labour.

The traditional method of transplanting is tedious to the labours as there is a stooping position throughout the time of transplanting. Besides, approximately 30% of the total labour requirement for rice production is for transplanting of paddy (Anon., 1978).

Garg et al. (1997) stated that higher and more stable yield was obtained from transplanted rice than direct seeded rice in India. In most states in India, transplanted rice has 10 to 20% greater yield than broadcasted rice. Besides, transplanting has some added advantages as compared to direct seedling i.e. better water and weed control, uniform ripening and less lodging.

Salazar *et al.* (1985) reported that hand transplanting is highly labour intensive and the high requirement of labour often results in labour shortage during the planting season.

2.2 DEVELOPMENT OF RICE TRANSPLANTERS

Stout (1968) stated that around 1950, a hand transplanting aid was developed and used in Taiwan. It was a simple aid which comprises of an iron rod with a fork forged on one end. A wooden handle was attached on to the other end of the rod. It had a length of 45 cm. Two to four plants were picked by the fork and the tool was dipped into mud and withdrawn leaving the seedlings in its place. This transplanting aid had to an increased rate of transplanting by about 20 percent, but as it requires considerable skill and experience it soon became obsolete. The main disadvantage of this tool was the depth of planting could not be adjusted by the operator. This was overcome by adding a small plate at right angles, but still it did not become popular.

Mandhar (1975) fabricated a three-row transplanting aid for paddy. It comprised of main frame, seedling tray, a retainer at the base, three planting fingers and an actuating mechanism. The device required about 300 man-hr per ha which practically saved no labour.

In the period of 1974-1975 a study was conducted for the first time in India, two different types of Japanese transplanters have been tested and evaluated at CFMTTI, Budni. Both were self –propelled (small petrol engine operated) two –row (fixed spacing) walking type. Because of the necessity of the special mat type seedlings and field condition as per the manufacturer, the machine could not pick up (Anon., 1975).

According to Kurup and Datt (1981), the timeliness of transplanting was considered as necessary for optimising the yield and there has been a spread in realisation among paddy growing countries to design and develop transplanter capable of performing precise and transplanting of paddy seedlings at an economically feasible level.

Igberka (1984) studied the development in mechanisation of paddy production. It was carried out through literature search, visits and communication. In developed countries, paddy production was completely mechanised, while most of the farm operations in paddy production in developing countries were still done by manual labourers. Japan has developed some small motorized machines which were reportedly sufficient for the small scale farming in poor countries.

Studies on the five-row and the six-row IRRI manually operated paddy transplanters were conducted in Kerala between a period of 1984 and 1990. After standardising the method of mat type seedlings, it has been observed that the 6-row paddy transplanter gave a field capacity of 0.017 ha per hour with a field efficiency of 85 percent and an economical saving of Rs. 600 per ha. A necessity for the development of higher field capacity transplanter was observed (Anon., 1990).

In Kerala Agricultural University, the IRRI 5- row and 6- row rice transplanters were intensively tested from 1982 onwards. Minor modifications and adjustments were carried out. After conducting preliminary field trials with 6-row rice transplanters, the unit was found to give satisfactory performance. But production of mat type nurseries as per the specifications was found to be difficult in actual field conditions (Anon., 1990).

Bainu (1990) modified an IRRI 6-row paddy transplanter designed for mat type nursery and tested for conventional seedlings. The field trails was done at instructional farm of KCAET Tavanur. The test results showed that the field capacity was improved from 0.013 ha hr^{-1} to 0.016 ha hr^{-1}. The field efficiency was also improved from 48.26% to 56.87%.

Devnani (1990) developed a self propelled riding type paddy transplanter using mat type seedlings at Ludhiana. It has a field capacity of 0.20 ha per hour and a cost of around Rs. 25000. The performance of the machine was remarkable when seedlings was properly prepared and are 20 to 28 days old. The mechanical transplanting of paddy was feasible only in the regions where there was a control of water in the fields and also where the farmers were ready to accept raising of mat type seedling for successful operation of the machine.

The Srilankan version of IRRI paddy transplanter (Mark 2) was experimentally used in Philippines. It was thoroughly suited to paddy framings in South-East Asia and in several regions of Philippines. The successful adoption of

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Mark 2 transplanter was achieved by the proper training given to the farmers in modern techniques and in repair and maintenance (Anon., 1991).

Prakash (1995) conducted a study on APAU paddy transplanter and has evaluated it after rectifying its defects at KCAET instructional farm, Tavanur. Based on the field experiences and considering all the problems in APAU paddy transplanter, an improved version of power tiller operated paddy transplanter was developed and fabricated at KCAET, Tavanur. The conventional root washed paddy seedlings ready for manual transplanting were used. The average field capacity was found to be 0.13 ha hr^{-1}. A reduction of 296 man- hr ha^{-1} which is 92.5% was achieved for transplanting operation alone compared to manual transplanting.

Chinese 8 row 'Yanji' transplanter marketed by VST Agro-inputs, Bangalore and was initially tested by the Agricultural Engineering Division of Regional Agricultural Research Station, Pattambi and came out with the finding that even though the row spacing of the machine is different from the recommended spacing there was no significant difference in yield (Anon., 1997).

2.3 AGRO-ECONOMIC ANALYSIS OF RICE TRANSPLANTERS

For planning and implementing a proper mechanization strategy, agro-economic analysis of transplanters is essential. Regina and James (2012) conducted an agro-economic analysis of rice transplanters in Kerala. The significant economic parameters were worked out *vis-a–vis* the agro-climatic situation for three different rice transplanters *viz.,* 8-row riding type, 4-row walk behind type and 6-row 4-wheel riding type. The deviation of cost of operation with respect of annual working hours and effective annual area were analyzed to develop a plan for mechanization of rice transplanting. The seasonal command areas as well as Break Even Hours (BEH) and Break Even Areas (BEA) for the different machines have also been estimated. They found that the total cost of operation could be reduced by 16.3% in the machine transplanting system compared to manual transplanting. The net profit was worked out considering that the average yield is 4500 kg ha^{-1}. The net profit from cultivation has been

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increased by 129 per cent in machine transplanting system with respect to that from less mechanized system, even though the other operations were done manually. The cost benefit ratio also had augmented i.e. from 1.13 of less mechanized system to 1.35 of machine transplanting system.

Munnaf *et al.* (2014) conducted a techno-economic performance of imported Kukje self-propelled rice transplanter and they found out that performance of the Kukje self-propelled rice transplanter was acceptable and the labour requirement was 1.4 man days per ha as against 25 in the case of manual transplanting. They recommended that the machine transplanting can be economical if the area to be covered is 10 ha or above per year. So, it is possible to increase the production per ha and to lessen the cost of paddy transplanting by mechanization to approximately half the cost of manual transplanting provided the machines are used for their maximum hours in a year.

James and Regina (2015) conducted a techno-economic appraisal for strategic planning of rice mechanization in Kerala. They found that group mechanization on *padasekharam* basis is the best choice for use of costly machines. The assessment of machinery requirement should be based on scientific analysis to arrive at economically sound decisions on their purchase and use.

2.4 TRANSPORT WHEELS OF AGRICULTURAL MACHINERY

Plackett (1985) reported that a pneumatic tyre is a structural vessel which contains a volume of air under pressure in order to bear the vertical load imposed by a vehicle. On interaction with the soil it can be acted in either of two ways. If the effective stiffness of the tyre is larger than the highest soil normal stress calculated, assuming that the wheel does not deflect, and then the tyre will work as a rigid wheel. Alternatively, if the effective stiffness of the tyre is smaller than the maximum normal stress, then the tyre will act as a deflected wheel. Deflection and sinkage could be found out from the input values of tyre stiffness (T) and soil strength (S) by drawing a perpendicular line on to the horizontal scales from the intersection of the lines representing T and S values as shown in Figure 2.1.

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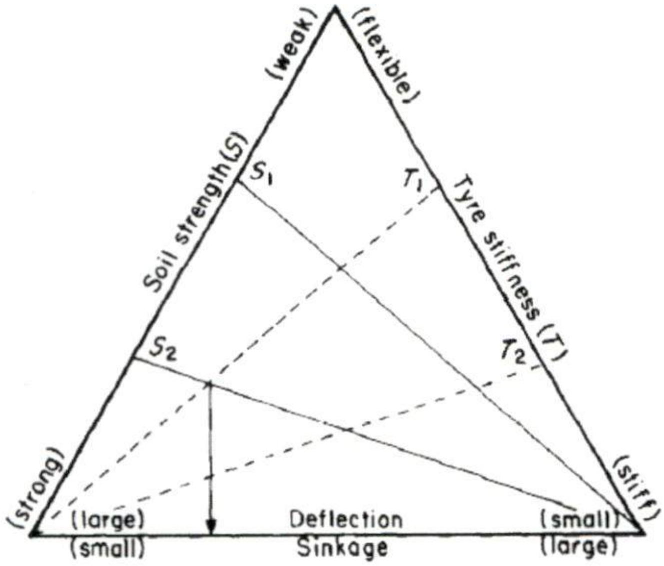

Figure 2.1 Schematic representation of the relationship between tyre stiffness, soil strength, sinkage and tyre deflection

Wang *et al.* (1993) conducted several experimental studies of open lugged wheel-soil interaction, mostly based on the condition of constant slip and sinkage. As a result, the reaction force to lugs appears to be equal to the soil cutting resistance to a metal surface. However, the analyses based on such methods do not appear to represent the actual lugged wheel-soil interaction especially when the lugs are spaced widely. The actual motion of a lugged wheel is determined by the interaction between lugs and soil with some load on the wheel axle. An experimental device for a model lugged wheel was created to examine the characteristics of the interaction between a lugged wheel and soil. Experiments were done under several test conditions of soils including paddy soil with a hard pan. The result of both theoretical and experimental data showed that slip and sinkage of a lugged wheel fluctuated with rotation angle, of which the period is equal to the angular lug spacing. In each test soil condition used, the motion of the lugged wheel and the reaction forces acting on each lug from the soil for a free sinking wheel were different from that of the condition of constant slip and sinkage. The motion of the lugged wheel is affected by the hard pan, so the soil reaction forces would be different from those of the soil conditions without a hard

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pan. Also the slip and sinkage of an open lugged wheel fluctuated periodically under constant vertical and drawbar load.

Weise *et al.* (2000) conducted an investigation of the turning behaviour of a self propelled rice transplanter and found out that the relationship between steering angle and turning radius for a paddy field vehicle with narrow wheels and a short wheelbase varied very much from the theoretical values. In very soft topsoil of a flooded paddy field, lateral support for the small and narrow wheels is feeble. This may be due partially to the form of the wheels which are more or less rigid and which are arranged with rubber lugs perpendicular to the direction of travel, thus providing only moderately small lateral support for the wheel on a flooded paddy field. They recommended that better control can be achieved through improved lateral guidance capability of the wheels by the use of V-shaped array of the lugs similar to the lugged wheel of tractors.

Raper (2005) found that varying configurations of tyres and tracks differ in their ability to produce tractive forces. The tractive elements also changes in the way that they crash the soil with some causing more soil disturbance than others. This soil disturbance consists of soil compaction and rut formation which negatively impacts rainfall infiltration, rooting, and crop production while potentially increasing soil erosion and runoff. A direct cause-effect relationship between vehicle traffic and crop response is very difficult to establish due to the existing soil conditions, differences in climate, differences in annual precipitation, differences in soils, spatial variability within fields, differences in crops, differences in crop varieties, and differences between various forms of vehicle traffic elements. Traffic is only possible when soil moisture is less than 60% of field capacity. Vehicle traffic conducted when soil moisture is greater than approximately 60% of field capacity can lead to excessive soil compaction that may be battled for many cropping seasons.

2.5 DEVELOPMENT OF APPLICATOR ATTACHMENTS

Proper design and selection of components are essential for satisfactory operation of applicators for plant protection and nutrient application.

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2.5.1 Selection of components and their parameters for agricultural spraying

Kepner *et al.* (1955) suggested that nozzle distribution pattern should be determined in the laboratory by spraying it on a surface that consist of a series of adjacent slopping 'v' or crust and trough. Measuring the liquid collected from each nozzle at the deposition level will give the spray pattern.

Smith and Stom (1976) stated that drift potential can be decreased by reducing the number of small droplets. The uniformity of row to row droplet density and mean diameter in target area is raised by increasing the size of droplets.

Winterfield and Boving (1980) found out that an asymmetrical nozzle array does not enhance uniformity of distribution and effective swath width is reduced compared with symmetrical nozzle array, which gave reasonably regular rate of variation.

Trefan (1984) reported that the quality of field spraying is established primarily by the functioning of nozzles mounted on the boom. Different nozzles could be selected by laboratory tests, but during operation in the field abrasion or clogging of the nozzle tips affected output and spray distribution.

Richardson *et al.* (1986) described an evaluation of a patternator for evaluating lateral distribution of liquid from single nozzles or small booms. Liquid from the individual channels on the patternator table was accumulated in tubes and measured by weighing on an electronic balance, linked directly to a microcomputer. Substantial variation in pattern occurred between successive runs with individual nozzles: the coefficient of variation from seven different nozzles ranged from 3.27% to 9.15%; this may be due to the turbulence in liquid flow within the nozzle. The pattern acquired from sintered alumina nozzles was better than that with brass nozzles. The Overall pattern from a boom was less variable than that obtained from single nozzles.

Juste *et al.* (1990) carried out a research to find out the design factors of spraying apparatus of boom sprayer for low volume application. They selected appropriate nozzles and determined effective swath, spraying height and nozzle spacing for row crop spraying.

Dekeyser *et al.* (2014) conducted a study on seven orchard spray application techniques to find out within-tree deposition quality and off-target losses to the ground and behind the target trees. The studied spray techniques included different types of sprayers, fan speeds and air deflector settings. Results revealed that spray application technique has an important role on spray deposition. Sprayer design caused vital differences in spray distribution and off-target losses. A significant portion of the spray liquid was lost to the ground and directly behind the trees with all spray techniques. The axial fan sprayer and the sprayer with individual spouts caused higher ground deposits than the cross-flow sprayer. The cross-flow sprayer on the other hand gave higher losses behind the trees, especially when a high fan speed was applied.

2.5.2 Development of applicator attachments

Pappan *et al.* (2012) developed a herbicide applicator attachment for Yanji-Shakthi paddy transplanter for applying pre-emergent herbicides at the time of planting. The herbicide applicator consists of a positive displacement pump. The pump was placed on the main frame of the paddy transplanter which is 80cm in front of the operator's position. The pump was directly operated by the paddy transplanter clutch pulley by extending the main driving shaft. A cam was provided at the end of the extended main shaft for converting rotary motion to reciprocating motion. The pump gets drive from the extended shaft which could be engaged by clutch lever.

A tractor drawn combination implement for dry seeding of rice along with application of pre-emergent herbicides was developed at Krishi Vigyan Kendra Palakkad (Anon., 2013). The sprayer system was driven electrically, power being drawn from the battery of the tractor. The system could reduce the cost of cultivation in dry seeded system.

An electrically operated herbicide applicator attachment to 8- row single wheel type rice transplanter was also developed at Krishi Vigyan Kendra-Palakkad (Anon., 2013). The three nozzles fitted behind the seedling tray could apply pre-emergent herbicides uniformly at the required rate. The system could be

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easily attached to the transplanter and could be removed easily. The low cost attachment required mechanical modifications for the transplanter.

Dixit *et al.* (2014) conducted a study to increase the usage of paddy transplanter by replacing transplanting unit of the machine with a spraying unit. The laboratory assessment of the sprayer was done at varying PTO speeds at different gears. Different PTO speeds produced were 230 rpm at first gear with forward speed of 1.60 km h^{-1}, 380 rpm at second gear with forward speed of 1.9 km h^{-1}, and 440 rpm at third gear and forward speed of 2.4 km h^{-1}. There was considerable difference in the discharge and angle of spray of individual nozzles of the same make and specifications. Swath width increased with increase in PTO speed, forward speed and gear. The best arrangement for spraying the pesticides was found to be at gear III, with forward speed of 2.4 km h^{-1} and PTO speed of 440 rpm.

2.5.3 Nozzles

Nozzles are designed to give different rates of discharge, angle of spray and spray pattern. Nozzles are classified according to the type of spray pattern (Singh, 2017). Standard nozzles are usually hydraulic energy nozzles which are widely used in manually operated sprayers. Hydraulic nozzles can produce droplets with volume mean diameter 150-400 microns at a minimum pressure of about 1.0 kg cm^{-2}.

2.5.3.1 Hollow cone nozzle

Hollow cone nozzles produces fine droplets and are sometimes referred as disc and core type. This type of nozzles is used to apply insecticides or fungicides where plant foliage penetration and complete coverage of leaf surfaces is essential. According to Singh, (2017) they operate at pressures ranging from 0.28-0.69 MPa. The spray angle is adjustable between 30° and 120°.

2.5.3.2 Solid cone nozzle

The solid cone nozzle produces large droplets at low pressure and is used mainly for high volume spraying of chemical. The constructional features were described by Singh, (2017). The spray angle ranges from 20° -30°. The nozzle is

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recommended for soil-incorporation of herbicides and operates at pressures between 0.103-0.275 MPa. For obtaining optimum uniformity the nozzles should be angled 30° with a spray overlap of 100 per cent.

2.5.3.3 Flood jet nozzle

These nozzles are recommended for applying suspension fertilisers where clogging is a potential problem. It produces large droplets at low pressure range of 0.070-0.17 MPa and medium droplets at higher pressures in the range of 0.103-0.62 MPa. Thus, a flood jet nozzle helps in reducing the chemical drift. These nozzles have spray angle from 70° -160°. Nozzles can be set at 38-45 cm above the target and nozzle spacing closer than 152.5 cm. It is used for fertiliser and post emergence herbicides.

2.5.3.4 Fan nozzles

The fan nozzles are widely used for spraying pesticides as band and broadcast applications. Nozzles are positioned on boom sprayers for broadcast applications, so that their output overlaps. These nozzles falls into several categories as described below.

a) ***Flat fan nozzles***

It is used for all types of fertilizers, insecticide application and largely for herbicide applications. This is a conventional type of nozzle that produces medium size droplets of 10 to 450 μm for providing even coverage. Spray quality ranges from fine to medium at 0.103-413 MPa. The standard flat-fan nozzle operates normally between 0.21-0.41 MPa with an ideal range of 0.21-0.28 MPa. Most of the flat fan nozzles were designed to use less spray fluid to allow overlap with the adjacent nozzle without increasing the application rate.

b) Even flat-fan nozzles

These nozzles ensure uniform coverage across the width of spray pattern. They are used for banding and should not be used for broadcasting operations. The bandwidth can be controlled with the nozzle-release height and the spray angle.

c) Extended-range flat-fan nozzles

This nozzle is ideal for uniform distribution at lower operating pressures for drift control. The extended-range flat-fan nozzle provides fair drift control when operated at a pressure less than 0.21 MPa. It provides an excellent spray distribution over a wide range of 0.103-0.41 MPa pressure.

d) Twin-orifice fan nozzle

It is suitable for application of post-emergence herbicides, insecticides, and fungicides. This nozzle produces two types of spray patterns, one with 30° forward and another with 30° backward. The droplets are small due to atomising by two smaller orifices. The two spray directions and smaller droplets improve coverage and penetration. It is usually operated between the pressure ranges of 0.21-0.41 MPa for obtaining fine droplets. The spray patterns for various types of nozzles are shown in Figure 2.2.

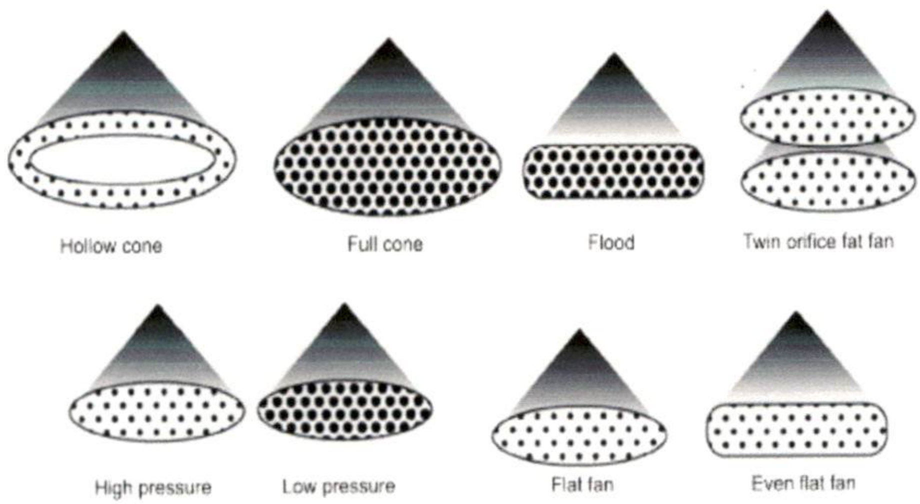

Figure 2.2 Spray patterns for various types of nozzles

2.5.3.5 Adjustable nozzles

Adjustable nozzles are generally used with manually operated foot sprayers and rocking sprayers. This nozzle can produce diverse spray patterns such as solid cone, hollow cone and jet due to its capability to produce various spray patterns with different spray angles. It is also used in high pressure hydraulic sprayers for application of chemicals on trees.

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2.5.3.6 Double swivel nozzles

These nozzles were used for high volume spraying in two different directions at a time. This has two swivel nozzles instead of one, capable of independent movement. It is useful for spraying chemicals in row crops.

2.5.3.7 Air induction (twin fluid) nozzles

Singh, 2017 reported that air induction nozzles are flat fan nozzles where an internal venturi creates negative pressure inside the nozzle body. These nozzles are expensive nearly three times the cost of a conventional flat-fan nozzle. It works by sucking air into the nozzle through the two holes in nozzle side, mixing with the spray liquid. The emitted spray contains large droplets filled with air bubbles, and virtually no fine, drift-prone droplets. The droplets explode on impact with leaves and produce similar coverage to conventional, finer sprays. They are only available at 110^{o} fan angle.

2.5.3.8 Low-drift nozzles

Low-drift nozzles create larger-size droplets than conventional nozzles. The larger droplet sizes are less prone to drift, reducing environmental and operator contamination.

2.5.3.9 Hot tube nozzles

This technique is used in ultra low volume spraying of chemicals for the control of insects, pests and also fogging for public health purposes. These nozzles works by introducing the chemical into the hot air stream where it vaporises due to high temperature of air. This vapour form of chemical condenses and changes into fog of fine droplets as soon as it emerges out of the nozzle due to comparatively low ambient temperature.

2.7 PSEUDOMONAS APPLICATION IN RICE

Pseudomonas fluorescens strains appear to be promising for the induction of induced systemic resistance. In addition to inducing plant defence genes, they also promote the growth and development of plants and hence referred as plant growth promoting rhizobacteria. Investigations on mechanisms of biological

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control by fluorescent pseudomonas have revealed that different strains protect the plants from various plant pathogens in several crops by inducing systemic resistance (Nandakumara *et al.*, 2001)

The Sheath blight disease caused by *Rhizoctonia solani* (Kuhn) and leaf folder insect *Cnaphalocrocis medinalis* (Guenee) are the significant production constraints of rice in South and South East Asia and other parts of world (Ou, 1985; Dale, 1994).

Genetic resistance is not available in rice sheath blight disease Bonmann *et al.* (1992). Due to this, in recent years the focus is shifted towards biological control of insect pests and diseases.

Commare *et al.* (2002) found out that chemical treatments reduced the sheath blight disease and insect incidence in rice. Pseudomonas application played a dual role by protecting the rice plants as well as promoting the growth of plants, which eventually led to better biomass and yield in comparison with the chemical treatments.

Ganeshan and Kumar, (2006) reported that *Pseudomonas fluorescens* is one of the proven biological control agent. Many success reports by several scientists around the world have depicted different *Pseudomonas* strains able to drastically control a number of fungal, bacterial and nematode diseases in cereals, horticultural crops, oil seeds and others. The efficacy of bacterial antagonism in controlling diseases was often better than with fungicides. However, the bacterial antagonism in combination with fungicides sometimes enhanced efficacy in controlling diseases. In addition to disease control, treatments also improved seedling health and yields of crops. Peat soil was found to be the best substrate followed by farmyard manure and gobar gas for colonization of *P. fluorescens*.

Jeyalakshmi *et al.* (2010) conducted field trials to standardize the method of application of *Pseudomonas fluorescens* (commercial formulation) under direct seeded wet sowing rice in randomized block design with fourteen treatments and three replications. They found out that treatment combinations recorded an increase in plant height, total number of tillers, productive tillers and yield over the application of *Pseudomonas* alone. Seed treatment with *Pseudomonas* and soil

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application on 30 days after sowing reached 50 per cent flowering a week earlier than other.

According to Elekhtyar (2015) *Pseudomonas* is able to drastically increase the yield of rice. Soil and plant health can be improved through plant growth-promoting rhizobacteria and crops rhizospheric interactions. Plant growth-promoting rhizobacteria and *Pseudomonas* not only promoted crop growth but also increased the resistance against pathogens.

2.8 MICRONUTRIENTS APPLICATION ON RICE

Zayed *et al.* (2011) conducted a study to find out the effect of Zn^{+2}, Fe^{+2} and Mn^{+2} as single or combined application in soil to the rice (Sakha101 as moderately salt tolerant rice variety) growth and yield. The treatments incorporated Zn^{+2}, Mn^{+2} , Fe^{+2}application as soil single treatments or Zn^{+2} + Mn^{+2}, Zn^{+2} + Fe^{+2} , Mn^{+2}+ Fe^{+2} and Zn^{+2} +Mn^{+2} + Fe^{+2} as combined applications through soil as well as a comparative treatment of commercial compound (14%Mn^{+2}+12%Fe^{+2}+16%Zn^{+2}) was applied twice at 20 and 45 days after transplanting as foliar spray. The main study results showed that the application of the three tested micronutrients as single or a combination significantly improved rice growth of Sakha 101 rice variety in two seasons. Dry matter production, leaf area index and chlorophyll content as well as plant height and panicle length were significantly higher when rice plant received the micronutrient compared to the control. Rice grain yield, straw yield, harvest index and yield components; panicle numbers, panicle weight, filled grains/panicle and 1000-grain weight were significantly increased by application of micronutrients application. The combination of Zn^{+2} +Fe^{+2} + Mn^{+2} gave the highest values of most studied traits without any significant differences with those produced by foliar spray twice. It could be concluded that micronutrient application especially through foliage under saline soil conditions is beneficial for rice growth and yield under such circumstances.

Das (2014) reported that micronutrient refers to the relative amount of a nutrient that is required for plant growth. It takes part in metabolic activities,

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enzymatic process or catalysts etc. Thus these all directly and indirectly help in plant growth and development. There are 8 essential plant nutrient elements defined as micronutrients like boron (B), zinc (Zn), manganese (Mn), iron (Fe), copper (Cu), molybdenum (Mo), chlorine (Cl) and silicon (Si). They constitute in total less than one percent of the dry weight of most plants. Organic sources like farm yard manure, compost, vermicompost etc. may contain less quantity of these nutrients but presence of these help the plant in their growth and development. They are also called trace elements or minor elements, required only in small amounts (5 to 200 ppm, or less than 0.02 percent dry weight). The visual symptoms may be caused by more than one nutrient. Deficiency of one nutrient may be related to an excess quantity of another. Nutrient deficiency symptoms are observed only after the crop has already suffered an irretrievable loss. When soil supplies more quantity of nutrient than the plant's requirement, plant shows toxicity symptoms.

Yadav *et al.* (2017) reported that the micronutrient mix of Kerala Agricultural University, "*Sampoorna-* KAU Multi mix" could substantially increase the yield of rice. The mixture contains most of the micro nutrients required by rice viz. Zinc (7%), Boron (4.5%), Copper (0.5%), Iron (0.2%), Manganese (0.2%), Molybdenum (0.02%), Magnesium (2%), Sulphur (6.5%), Potassium (15%). They recommended foliar spray in the nursery followed by further spraying at 30 days and 50 days after transplanting.

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Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The methodology adopted for conducting the agro-economic analysis of four-wheel riding type rice transplanters, development of new attachments to such a rice transplanter, experimental procedure and set-up used to evaluate the developed attachments are detailed in this chapter.

3.1 AGRO-ECONOMIC ANALYSIS OF A FOUR-WHEELED RIDING TYPE RICE TRANSPLANTER

3.1.1 Assessment of Agro-Climatic Situation in Central Zone

The rice growing seasons of Kerala are *Virippu*, *Mundakan* and *Puncha*. The period of different seasons are given in Table 3.1.

Table 3.1 Rice growing seasons of Kerala

Seasons	Period	
	From	To
Virippu(I Crop / Autumn)	April – May	September – October
Mundakan (II Crop / Winter)	September – October	December – January
Puncha(III Crop / Summer)	December – January	March – April

Source: KAU, 2016

According to Anon. (2017) the land area under paddy cultivation during *puncha* season was only 2,695 ha whereas that in *virippu* and *mundakan* season have crop area of 37,371 ha and 42,846 ha respectively (Appendix V). The land area under paddy cultivation in the central zone (kole lands not included) for *puncha* is very less. So *puncha* season was not considered for this analysis.

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3.1.1.1 Onset of monsoon and rainfall pattern relevant to transplanting paddy

The prediction of onset of monsoon from the year 2007 to 2015 by India Meteorological Department was collected and is presented in Appendix I.

Weekly normal rainfall is the average rainfall values over 30-year period. Weekly rainfalls of 8 Agro-ecological units (AEU) in Palakkad district in the central zone of Kerala were computed using the data collected from IMD and were used to estimate the weekly normal rainfall.

3.1.1.2 Crop varieties and their duration

The main paddy varieties used in the study area were *Uma, Jyothi* and *Prathyasha*. Among these Uma is the most commonly used variety. It is a medium-duration variety with duration of 115-120 days. *Jyothi* and *Prathyasha* are short duration varieties, with durations of 110-115 days and 100-110 days, respectively (KAU, 2016).

3.1.1.3 Probable date and duration of transplanting season

It was considered that the transplanting started only after receiving 200 mm of cumulative rainfall within a span of 3-4 weeks. From the weekly normal rainfall and the chart of standard meteorological weeks (Appendix II), the probable date of transplanting was determined.

This data was analysed to determine probable date and duration of transplanting. For this analysis, week on which the cumulative rainfall having more than 200 mm was found out from the weekly normal rainfall table (Appendix III). From that week onwards, duration of 3 weeks was provided for land preparation.

The starting date for transplanting *virippu* season was obtained based on the methodology described above. For finding the last date of transplanting in the *virippu* season, crop durations of the three different rice varieties were considered. In general the nursery was raised by the farmers for afford of 3 week which can be used for land preparation of main field. Hence, the duration of 21 days provided for the ageing of nursery was reduced from the overall crop duration of the varieties. Thus the harvest date of the *virippu* season was obtained. It was

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considered that the harvest was scheduled before heavy rains during the North-East monsoon because high rainfall during the time of harvest will adversely affect the crop. Hence the probable last date of harvest in the season for a particular agro-ecological unit was fixed at the last day of the week preceding the week during which the normalised rainfall is equal to or more 100 mm. Thus, the start and end dates of transplanting in *virippu* season was obtained. The same procedure was repeated for all the agro-ecological units.

A turnover period of 10 days after harvest of first crop was considered based on the information collected from the farmers. This duration is added to the harvest date of the *virippu* season which gives the start date of transplanting for *mundakan* season. According to IMD (2017), *mundakan* season is from 34th to 8th meteorological week. Based on this the 44th meteorological week is taken as the last date of transplanting of the *mundakan* season and the probable date of transplanting was found out using this methodology. The same methodology was followed for every AEU's.

Possible working hours in a day was taken as eight hours. The duration of the transplanting season can be calculated by using the total days available for transplanting in a year and possible working hours in a day. The dates which were calculated was compared with the data collected from five *padasekharams* and variation between theoretically calculated and actual field conditions were analysed.

3.1.2 Economic Parameters of Machinery Use

The three types of four wheel riding type rice transplanters, viz. Yanmar Vp8D (TR_1), Yanmar Vp6D (TR_2) and Kubota NSPU-68C (TR_3) were selected for finding the economic parameters of machinery use. The methodology for economic analysis of agricultural machines recommended by Hunt (1977), James *et al.,* (2006) and James and Regina (2015) were adopted to develop a strategic guideline for the use of 4-wheel riding type rice transplanters with respect to the specific situation. The various parameters relevant in the analysis are listed below.

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i. Fixed cost

It is the annual ownership cost which occurs regardless of machine use. It includes depreciation, interest, insurance and taxes.

a) Depreciation

Depreciation is a cost resulting from wear, obsolescence, and age of a machine. Following formula can be used for computing depreciation:

$$D = \frac{P - S}{L \times H}$$

... (Hunt, 1977)

Where,

D = Depreciation, Rs/hr

P = Purchase price, Rs.

S = Salvage value, Rs.

L = Useful life, Years

H = Annual working hours

b) Interest

Following formula is used for computing interest:

$$I = \frac{P + S}{2} \times \frac{i}{H}$$

... (Hunt, 1977)

Where,

I = Interest, Rs. h^{-1}

P = Purchase price, Rs.

S = Salvage value, Rs.

i = Interest rate, fraction

H = Annual working hours

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c) Insurance, taxes and housing charges

These charges are computed on yearly basis, which is generally taken as 1 per cent of purchase price of the machine.

ii. Variable cost

It is defined as the operating costs which vary directly with the amount of machine use. It includes repair and maintenance cost, fuel cost, Lubricants and wages. Repair and maintenance cost is taken as 5 per cent of purchase price of the machine. Fuel cost is computed on the basis of actual fuel consumption during operation and the lubricant cost is roughly taken 30 per cent of the fuel cost. Wages are computed on the basis of actual wages of the workers.

3.1.2.1 Fuel consumption

Fuel consumption can be defined as the rate at which an engine uses fuel, expressed in the unit as litre per hour. For measuring this, the tank is filled to full capacity before and after the test. Amount of refuelling after the test is the fuel consumption for that particular duration. While filling up the tank, careful attention should be paid to keep the tank horizontal and not to leave empty space in the tank (Figure 3.1).

Figure 3.1Measurement of fuel consumption

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3.1.2.2 Theoretical field capacity

It is the function of speed of transplanter and the width of operation expressed in ha hr^{-1} and it was calculated by the following equation:

$$\text{TFC} = \frac{w \times s}{c}$$

... (Metha *et al.,* 1995)

Where,

TFC = Theoretical field capacity, ha h^{-1}

w = Operating width of the transplanter, m

s = Transplanting speed, km h^{-1}

c= Constant, 10

3.1.2.3 Actual field capacity

The actual or effective field capacity is the actual rate of coverage by the machine i.e., area covered, based upon the total working time and it can be calculated by the following equation:

$$\text{AFC} = \frac{A}{T}$$

... (Mehta *et al.,* 1995)

Where,

AFC = Actual field capacity, ha h^{-1}

A= Total transplanted area, ha

T= Total operating time for transplanting, h

3.1.2.4 Field efficiency

It is the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity and it can be calculated by the following equation:

$$\text{Ef} = \frac{\text{AFC}}{\text{TFC}} \times 100$$

... (Mehta *et al.,* 1995)

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Where,

E_f = Field efficiency, %

AFC = Actual field capacity, ha h^{-1}

TFC = Theoretical field capacity, ha h^{-1}

3.1.2.5 Hourly operation cost

Hourly fixed cost (HFC), Rs. h^{-1} was calculated for different Annual Operating Hours (AOH), h per annum. Hourly Variable Cost (HVC) Rs. $h^{-1}$was calculated using the data collected on fuel consumption, lubricant cost, operator's wages, and repair and maintenance charges. The Hourly Operation Costs, (HOC) were calculated as the sum of HFC and HVC values for different AOH.

3.1.2.6 Unit area operating cost

The Unit Area Operating Costs, Rs. ha^{-1} (UAOC) with respect to the variation of annual working hours were analyzed. From the HOC and the actual field capacity, the UAOC can be found out (James *et al.*, 2006)

3.2. DEVELOPMENT OF TRANSPORT WHEEL FOR FOUR WHEELED RICE TRANSPLANTER

Transplanters available in the market are presently provided with lugged rubber wheels for operation in puddled field. These wheels can get easily damaged if used on firm ground for transit from one field to another. The development of the transport wheel system was done based on the Kubota make 6 – row transplanter (Kubota NSPU – 68C). The technical specifications of the model are given in Table 3.2

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Table 3.2 Technical specifications of Kubota NSPU-68C rice transplanter

Model				NSPU-68C
Drive type				4- Wheel drive
Dimensions	Overall length (mm {inch})			3000{118.11}
	Overall width (mm {inch})			2210{87.01}
	Overall height (mm {inch})			2570{101.18}
	Minimum ground clearance (mm {inch})			430{16.93}
Weight (Kg)				590
Engine	Model			GZ460-P-CHN
	Type			Water-cooled, 4-cycle, 2-cylinder OHC gasoline engine
	Total displacement (L {cc})			0.456 {456}
	Output revolution speed (kW {PS}/rpm)			Output/revolution speed (kW{PS}/rpm) 8.5{11.5}/3600 MAX [12.5 {17.0}]
	Applicable fuel			Unleaded gasoline for automobile
	Fuel tank capacity (L)			17
	Starting system			Starter motor
	Battery			12V, 24Ah [34A19L]
Travelling portion	Steering system			Integral power steering
	Wheel	Type	Front wheel	No- puncture tyre
			Rear wheel	Rubber lug wheel with thick rim
		00 x width	Front wheel (mm{inch})	650{25.59}X95{3.74}
		00 x rim width	Rear wheel(mm{inch})	900{35.43}X50{1.97}
		Tread	Front wheel (mm{inch})	1165{45.87}
			Rear wheel(mm{inch})	1200{47.24}
	Shifting system			Hydraulic transmission HST
	Number of shifting positions			HST Main Shift: Variable speeds for forward and reverse: No clutch [sub shift: 2 positions]

As the machine was four-wheel drive, for changing the wheels it was required to select the pneumatic wheel tyres having compatible dimensions as the lugged wheels. Pneumatic wheels having 900 mm diameter and having a load bearing capacity of 250 kg was not available in the market. For developing the transport wheel assembly the four-wheel drive was converted into two wheel drive and a special hub assembly was developed. The rear wheel was selected as the drive wheel.

Design considerations for wheel hub assembly

a. Front wheel assembly:

i. The base of the wheel hub assembly should be exactly the same size (160 mm) as that of the existing hub of the transplanter.

ii. A bearing assembly should be provided on the front wheel to convert the four wheel drive to rear wheel drive.

iii. The bearings should have enough load bearing capacity to bear the whole load acting on the front wheel.

iv. Square shaft of relevant size should be provided for connecting the hub and wheel.

b. Rear wheel assembly:

i. Hexagonal pipe of enough load bearing capacity is required as the driving shaft of the transplanter.

ii. A locking mechanism need to be provided to lock the wheel hub assembly without being detached from wheels while travelling.

iii. Wheel hub assembly should match the size of the pneumatic wheel selected.

3.2.1 Speed of Travel

The rice transplanting machine should have a specific range of speed of travel during the transport mode. The speed of travel of the transplanter with pneumatic wheels and lugged wheels were measured. For that, a distance of 20 m was marked with the help of poles on both ends (Figure 3.2) and the time taken to cover this distance was recorded using a stopwatch. The procedure was repeated five times and the average value was taken.

Speed of travel, S is given by:

$$S = \frac{D}{T} \times 3.6$$

Where,

S = Speed of the transplanter, km h^{-1}

D = Distance travelled, m

T = Time taken to cover 20 m distance, s

Figure 3.2 Speed of travel measurement

3.2.2 Centre of Gravity

The centre of gravity of an object is defined as the point through which the line of action of the weight always acts. For symmetrical objects it will be at the geometric centre. For objects having other shapes the position shall be calculated or measured experimentally (Studman, 1990).

Centre of gravity can be found out experimentally by several methods like suspension method, balancing method and weighing method. Among these balancing method was selected for determining centre of gravity of transplanters.

A platform scale of appropriate size was used to get the weight of the transplanter and the reactions acting on each wheel. The transplanter was placed on a level ground and the weighing balance was placed below each of the wheels to measure the respective reactions on each wheels. From these reactions, the transplanter was found to be a symmetric machine. Then the front wheels were placed on an elevated plane of 21.5cm height. The experimental setup made for calculating centre of gravity is shown Figure 3.5. The reaction on the front wheels at the elevated position, wheel base of the transplanter and radius of front and rear wheels were measured.

The centre of gravity was found using the methodology developed by Lal and Datta (2011).

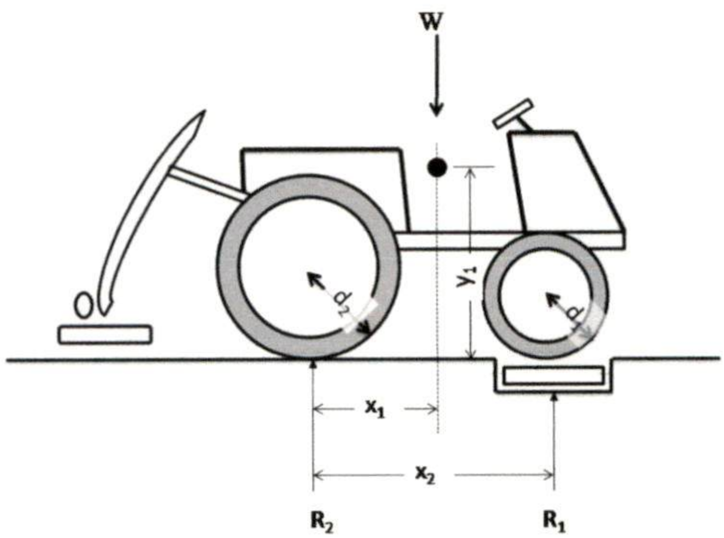

Figure 3.3 Transplanter on level ground

If R_1 and R_2 are the soil reactions against the front wheel and rear wheels on level ground as shown in Figure 3.3.

Then taking moment about B,

$$x_1 = (R_1 x_1)/ W$$

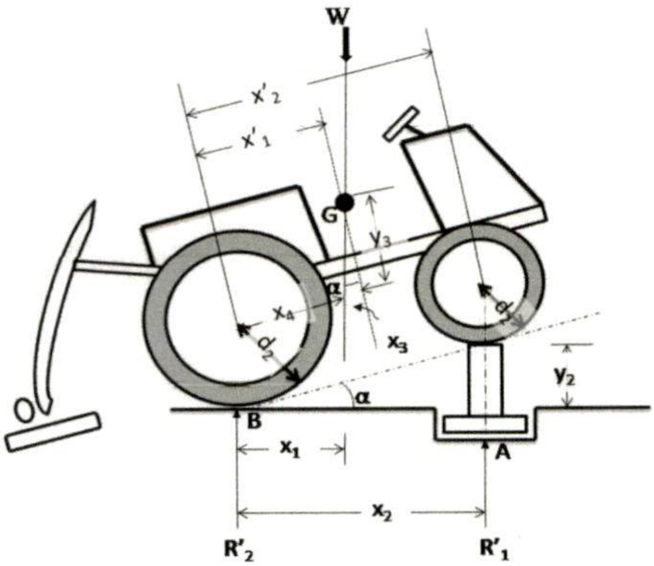

Figure 3.4 Transplanter in elevated position

Figure 3.4 shows the transplanter when the front wheels are lifted to 21.5 cm.

From the geometry,

$$x'_2 = [x_2 + (d_2 - d_1) \tan \alpha] \cdot \cos \alpha \quad \text{... (1)}$$

Now $\sin \alpha = y_2 / (x_2 - d_1/2 \sin \alpha)$

From the above equation value of α can be found out and put the value of α in equation (1), then x'_2 can be found out.

Taking moment about B,

$$x'_1 = (R'_1 x'_2) / W \quad \text{... (2)}$$

From the geometry,

$$\tan \alpha = x_3/y_3 = (x_1 - x_4) / y_3$$

Or

$$y_3 = (x_1 - x_4) / \tan \alpha$$

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Again

$$\cos \alpha = x'_1 / x_4$$

Or

$$x_4 = x'_1 / \cos \alpha$$

Putting the value of x_4 in equation (2)

$$y_3 = (x_1 - x'_1/\cos \alpha) / \tan \alpha$$

Hence,

$$y_1 = d_2 + y_3$$

From these calculations we can point out centre of gravity of transplanter as x_1 cm ahead of rear axle and y_1 cm above the ground.

Figure 3.5 Experimental setup for finding centre of gravity

3.2.3 Stopping Distance

Stopping distance is the distance traversed by the transplanter from the point at which the brake pedal was actuated by application of pressure by the operator to the point at which the machine reached a complete stop.

The test was conducted on a plane, horizontal, dry and clean surface. The test was carried out at highest forward speed and lowest forward speeds by using both pneumatic and lugged wheels. A line is marked on the ground; at that point the brake is applied completely. The distance moved forward from the marked line to the point at which the transplanter is stopped was measured. The same procedure was repeated five times at maximum and minimum speeds.

3.3 DEVELOPMENT OFBIO-FUNGICIDES AND MICRO NUTRIENTS APPLICATOR SYSTEM

3.3.1 Design Considerations of the Applicator Attachment

Applicator attachment is intended for applying bio-fungicides and micronutrients on the mat nursery at the time of transplanting itself. The design considerations of the applicator attachment were as follows:

i. The essential components of the spraying system shall be a pump, tank, spray boom fitted with nozzles, hose pipes and other accessories necessary for spraying.
ii. The pump should be driven by 12 Volt DC power available from the battery of the transplanter.
iii. The pump should have sufficient discharge and develop required pressure.
iv. The system should enable uniform spraying.
v. There should be an arrangement to vary the spray height from 10 - 50 cm from loaded mat nursery.
vi. The operator should have to take minimum effort to operate the applicator unit.
vii. It should be cost effective, simple in operation and easy for maintenance.

3.3.2 Droplet Size Analysis

The spray droplet size was measured in the lab by providing a similar condition as that of field operation. The experimental setup for measuring droplet size was as follows:

Bromide Photo paper of size 5 cm ×5 cm was used for collecting the spray droplets. For pigmenting the spray fluid, Methylene Blue dye was used. Pigmented spray solution was prepared by dissolving 20 g of dry Methylene Blue

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dye in 1 litre of water. High resolution Scanner was used for scanning photo papers with 1200 dpi scan resolution. Computer based image analysis software Image-J-2016, Version 1.37.1 was used to analyse the scanned images and droplets.

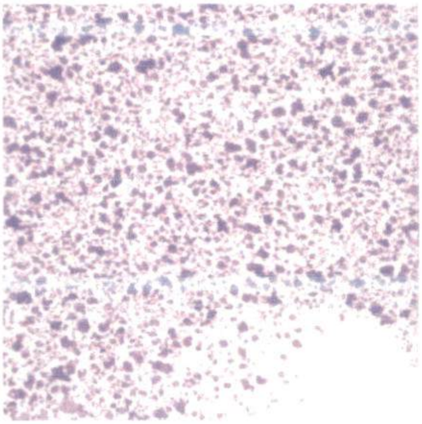

Figure 3.6 Scanned image of droplets

The Bromide photo paper was kept at a distance of 50 cm away from the spray nozzle for a fraction of second, perpendicular to the axis of spray nozzles. The treated photo papers were scanned for generating digital images and were fed to the Computer based image analysis software – Image-J-2016. The images (Figure 3.6) were processed in order to calculate the average range of droplet size.

3.3.3 Nozzle Selection

Selection of appropriate nozzles is an essential requirement for uniform spraying. Different types of nozzles were procured (Hollow cone, Solid cone and Flat fan) and the spray patterns of the nozzle type were observed using a spray patternator. The apparatus comprises of a corrugated metal sheet, over which the nozzles were fixed. The corrugated metal sheet placed below the nozzles acted as a device to divide the spray area transversely. The liquid flowing out through each corrugation was collected in a glass collecting tube.

From the patternator studies the spray width, spray angle, spray volume and the overlap needed, etc could be understood. The spray patternator arrangement is shown in Figure 3.7.

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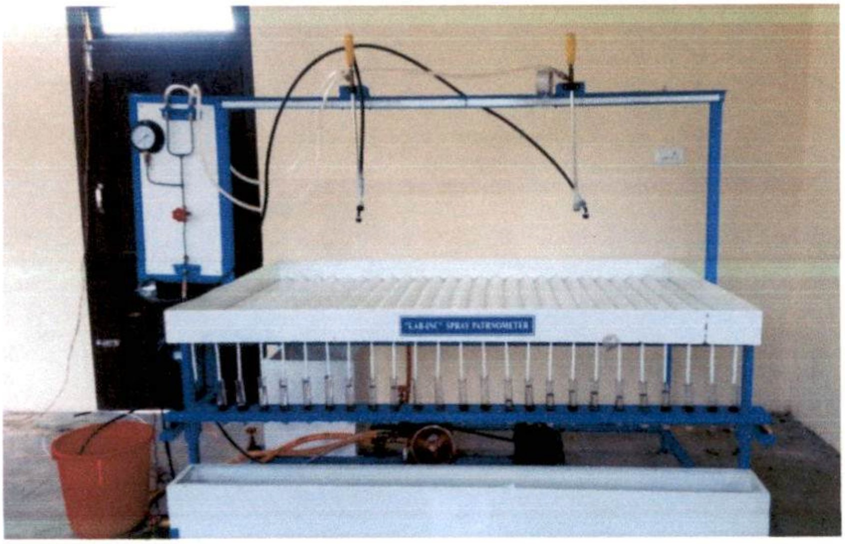

Figure 3.7 Patternator apparatus

The nozzle was centrally fixed on the patternator. The collecting glass tubes towards the left hand side were marked as L1, L2, etc. and those to the right hand side were marked as R1, R2, etc. The volume of water received in each tube was measured and recorded. The patternator observations were analysed for setting nozzles on the spray boom.

The seedling tray of transplanter had a width of 180 cm. The nozzle spraying measured spray width was divided to the width of the seedling tray will gives the number of nozzles required.

Length of the spray boom was taken as the same length of seedling tray bottom, i.e., 180 cm. The patternator observations were processed using Microsoft excel to get the nozzle configuration and spacing. The nozzle having uniform spray pattern was selected for the applicator. The spray distribution under different overlap distance was analysed and the optimum spacing giving most uniform spray pattern was selected. Nozzles were arranged linearly with the specified spacing and numbers.

3.3.4. Discharge of Applicator Attachment

The discharge of the pump, nozzles and applicator were measured. The discharge through pump, each nozzle and applicator were noted for a particular period of time. The discharge rate of each nozzle was calculated by using the formula:

$$\text{Discharge (l min}^{-1}\text{)} = \frac{\text{Volume of spray collected}}{\text{Time taken}}$$

3.3.5 Rate of Application at Rated Speeds

The seedling (mat nursery) tray of the transplanter was loaded with six mats of 65 cm length and 30 cm width. The time taken to plant this whole mat was recorded. The total discharge of spray fluid corresponding to this duration was estimated. Based on these observations, the dilution rate of different liquids to be applied was calculated.

3.3.6 Bio-Fungicide Application

The pseudomonas liquid which is available in the market in the brand name 'Poabs green' was used. The manufacturer's recommendation for dilution of liquid pseudomonas was 5 ml l^{-1}. For foliar application of pseudomonas the recommendation was 500 l ha^{-1}.The actual quantity of pseudomonas for one ha amounts to 2.5 litres. The spray volume required for 1 ha with the developed attachment was estimated at 201 litres. Hence each batch of 50 litres (tank capacity) required 625 ml of pseudomonas formulation.

The randomly selected test plots were observed regularly for fungal attack. The plant height was also observed on the 30^{th} and 90^{th} days after transplanting.

3.3.7 Micronutrient Application

For this study, the micronutrient applied was '*Sampoorna* KAU multimix' for rice developed by Kerala Agricultural University. It has been prepared according to the soil behaviour of Kerala. This can be applied through foliar spray and it is completely soluble in water. The major ingredients of the mix were Zinc (5 - 7%), Boron (3.5 - 4.5%), Copper (0.3 - 0.5%), Iron (< 0.2%), Manganese (< 0.2%) and Molybdenum (< 0.02%). The mix was diluted in water as per the recommendation of the Kerala Agricultural University, i.e. 5 g of *Sampoorna* mix was added to one litre of water. The actual quantity of *Sampoorna* for one ha

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amounts to 2.5 kg. The spray volume required for 1 ha with the developed attachment was estimated at 201 litres. Hence each batch of 50 litres (tank capacity) required 625 g of *Sampoorna* formulation.

The crop variety selected was Uma for the field experiment. The plots for micronutrients treatment was selected randomly in the experimental area. The statistical analysis was done using Paired T - test. The following attributes were considered to compare the treated and untreated plots:

i. Plant height

Plant height was recorded at 30^{th} and 90^{th} days and harvesting stage of crop in cm. Eight hills were tagged randomly in each plot for measuring the height. The height of plant measured from the ground level up to the tip of fully open leaf till the emergence of panicle and up to the neck of panicle after emergence of panicle.

ii. Total productive and unproductive tillers m^{-2}

The productive and unproductive tillers per unit area were observed by counting the number of tillers per hill and the number of hills m^{-2}.

iii. 100-grain weight

Cleaned grain sample was taken from each plot and 100 numbers of grains was counted from each sample and weighed using a digital weighing balance.

iv. Grain yield m^{-2}

The grains harvested from unit area were weighed using weighing balance.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

The results of the investigations carried out for agro-economic analysis of four wheeled riding type rice transplanters, the details of attachments developed to the transplanter and the results of the various laboratory and field tests conducted are described in this chapter.

4.1. AGRO-ECONOMIC ANALYSIS OF FOUR WHEELED RIDING TYPE RICE TRANSPLANTERS

4.1.1 Onset of Monsoon and Rainfall Pattern Relevant to Transplanting Paddy

The normal date of onset of the monsoon over Kerala is 1st June, with a standard deviation of eight days (Pai and Nair, 2009). According to India Meteorological Department (2017), the onset of monsoon in the year of 2016 was on June 10th, whereas was it was on 3rd June in 2015. Even though there was variability, first June was considered as the date of monsoon onset for the purpose of estimating the length of transplanting season in Kerala. The weekly normalised rainfalls were estimated for the 13 AEUs' in the central zone of Kerala and are shown in Appendix II.

4.1.2 Duration of Transplanting Season in different AEUs

The probable date for transplanting rice in *virippu* and *mundakan* season at different rice growing AEUs of Palakkad district was estimated as described in section 3.1.1.3 and depicted in Table 4.1. AEU 10-23 represents Palakkad district but the major rice growing areas are in AEUs 10, 22 and 23.

The onset of transplanting is based on the crop durations under various combinations of varieties. The date of start of transplanting in the *virippu* season was fixed based on climatic factors and was independent on the variety cultivated, where as the date varied in *mundakan* with respect to the duration of the variety used in *virippu*. Out of the three varieties popularly used, Uma had maximum duration of 115-120 days. Hence when the varietal combination in two successive seasons was Uma-Uma, the total crop duration was maximum.

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Table 4.1 Probable days available for transplanting rice in Palakkad district

AEUs	Seasons	Uma - Uma	Uma - Jyothi	Uma - Prathyasha	Jyothi - Jyothi	Jyothi - Uma	Jyothi - Prathyasha	Prathyasha - Prathyasha	Prathyasha - Uma	Prathyasha - Jyothi
AEU 10	Virippu	35	35	35	35	35	35	35	35	42
	Mundakan	35	60	74	35	65	79	35	73	73
	Total days	70	95	109	70	100	114	70	108	115
AEU 13	Virippu	14	14	14	14	14	14	14	21	21
	Mundakan	14	53	67	19	58	72	14	66	66
	Total days	28	67	81	33	72	86	28	87	87
AEU 14	Virippu	42	42	42	42	42	42	42	49	49
	Mundakan	42	67	81	42	72	86	42	80	80
	Total days	84	109	123	84	114	128	84	129	129
AEU 15	Virippu	21	21	21	21	21	21	21	28	28
	Mundakan	21	67	81	21	72	86	21	80	80
	Total days	42	88	102	42	93	107	42	108	108
AEU 18	Virippu	70	77	84	70	77	91	70	84	84
	Mundakan	70	77	70	70	77	91	72	84	91
	Total days	140	154	154	140	154	182	142	168	175
AEU 19	Virippu	42	49	56	42	49	63	42	25	73
	Mundakan	42	49	56	42	49	63	42	56	63
	Total days	84	98	112	84	98	126	84	81	136
AEU 22	Virippu	42	49	56	42	49	63	42	25	73
	Mundakan	42	49	56	42	49	63	42	56	63
	Total days	84	98	112	84	98	126	84	81	136
AEU 23	Virippu	35	42	49	35	42	56	42	49	56
	Mundakan	35	42	49	35	42	56	35	49	56
	Total days	70	84	98	70	84	112	77	98	112

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From Table 4.1 the maximum probable days available for transplanting at Palakkad district was obtained at AEU-18 with duration of 182 days, when the varietal combination was Jyothi-Prathyasha. This is due to meagre rainfall in the region after the South-West monsoon, as there is no restriction on duration imposed by high rainfall during harvest. But, this AEU has very small area under rice and hence need not deserve a major consideration. The estimated probable starting and ending dates for transplanting for the nine varietal combinations are shown in Appendix IV.

The maximum working hours were estimated based on the total available days for transplanting and it has been calculated as 1458 h. The minimum probable days available for transplanting were 28 days at AEU-13 for both Uma-Uma and Prathyasha-Prathyasha combinations. The minimum working hours were estimated based on the total probable days for transplanting and it has been calculated as 224 h for Uma-Uma and Prathyasha-Prathyasha varietal combinations in AEU-13.

The pertinent data gathered from the survey conducted in five *padasekharams* of Palakkad district are shown in Table 4.2. Only 63 percent of farmers adopt direct dry seeding during the *virippu* season and 97 percent of the farmers adopt transplanting in *mundakan* season.

Table 4.2 Duration of transplanting seasons in different *Padasekharams*

Padasekharams	**Transplanting days**			
	Virippu	***Mundakan***	***Puncha***	***Total***
Thrippatta	13	17	11	41
Koonathara	16	15	9	40
Parachattam kottadi	15	14	9	38
Kottekulam	13	17	10	40
Tiruvara	17	13	-	30
Mean	**14.8**	**15.2**	**7.8**	**37.8**

It was found that the major rice cultivation season was *mundakan*, during which 94 percent of the farmers raise the crop where as in *virippu* season only 72 percent of farmers take up cultivation. During *puncha* season the area cultivated is meagre due to many agro-ecological factors mainly accountable to non-availability of water.

Based on farmers perception on the days available for transplanting in each season (Table 4.2), average duration of transplanting in *virippu* and *mundakan* seasons were 14.8 and 15.2 days, respectively, whereas only 10 days was available in *puncha* season. The mean total duration of transplanting season in a year was 37.8 days. Based on this the Annual Operating Hours (AOH) available for a transplanting machine was calculated as 302, considering 8 h in a day as working hours. Hence it was inferred that the actual AOH in *padasekharams* of Palakkad district may be taken approximately as 300.

4.1.3 Techno-Economic Parameters of Machinery Use

Various economic and technical parameters of the three different rice transplanting machines are given in Table 4.3.

Table 4.3 Techno-economic parameters of rice transplanters

Parameters	Yanmar Vp8D	Yanmar Vp6D	Kubota NSPU-68C
HP	21	21	16.67
Capital investment, Rs.	17,68,000/-	15,50,000/-	14,00,000/-
Annual fixed cost, Rs.	2,74,038/-	2,40,253/-	2,17,000/-
Average fuel consumption, $l\ h^{-1}$	3.5	1.75	1.78
Operators wages, Rs. h^{-1}	1500	1500	1500
Fuel cost, Rs. l^{-1}	60.20	60.20	70.18
Row spacing, cm	30	30	30
Number of rows	8	6	6
Actual field capacity, ha h^{-1}	0.4	0.38	0.33

4.1.3.1 Annual fixed cost

The annual fixed cost (AFC) was found to be maximum (Rs. 2,74,038/-) for Yanmar Vp8D followed by Yanmar Vp6D (Rs. 2,40,253/-) and the minimum for Kubota NSPU-68C (Rs. 2,17,000/-). As a consequence of maximum annual fixed cost, Yanmar Vp8D had maximum fixed cost components viz. depreciation, interest, insurance and taxes.

4.1.3.2 Annual variable cost

The annual variable cost based on an AOH of 300 h was found to be maximum (Rs. 2,03,345/-) for Yanmar Vp8D, followed by Yanmar Vp6D transplanter (Rs. 1,65,355/-) and the minimum for Kubota NSPU-68C (Rs. 1,63,737/-). The fuel consumption of the Yanmar Vp6D was very low compared to the other two makes of transplanters. The difference in fuels used was another important factor to be considered. In both models of Yanmar make machines, the fuel used was diesel, whereas petrol was used in Kubota make machine.

4.1.4 Hourly Operational Cost of Rice Transplanters

The components of hourly operating costs of the three transplanters are shown in Figure. 4.1. In the case of all the machines, fixed cost was predominant when the AOH was low and at certain AOH both fixed and variable costs became equal. With further increase in AOH, the variable costs became predominant.

It was observed from Figure. 4.1 that fixed cost had more contribution in HOC than variable cost within the range of 50 to 400 AWH for Yanmar Vp8D transplanter. At the AOH of 400, fixed and variable costs had equal contributions in HOC, i.e. 50:50. The trend changed beyond 400 h and the percentage contribution of variable cost was found to increase to reach 67 percent at the AOH of 1000. Similar trends can be observed in the case of Yanmar Vp6D and Kubota NSPU 68C transplanters for which the predominance of fixed cost component prevailed over variable cost up to the equality point at AOH of 305 and 400, respectively. When the 1000 h point is reached, variable cost significantly predominated, contributing 71 percent and 66 percent of the HOC, respectively (Appendix VI).

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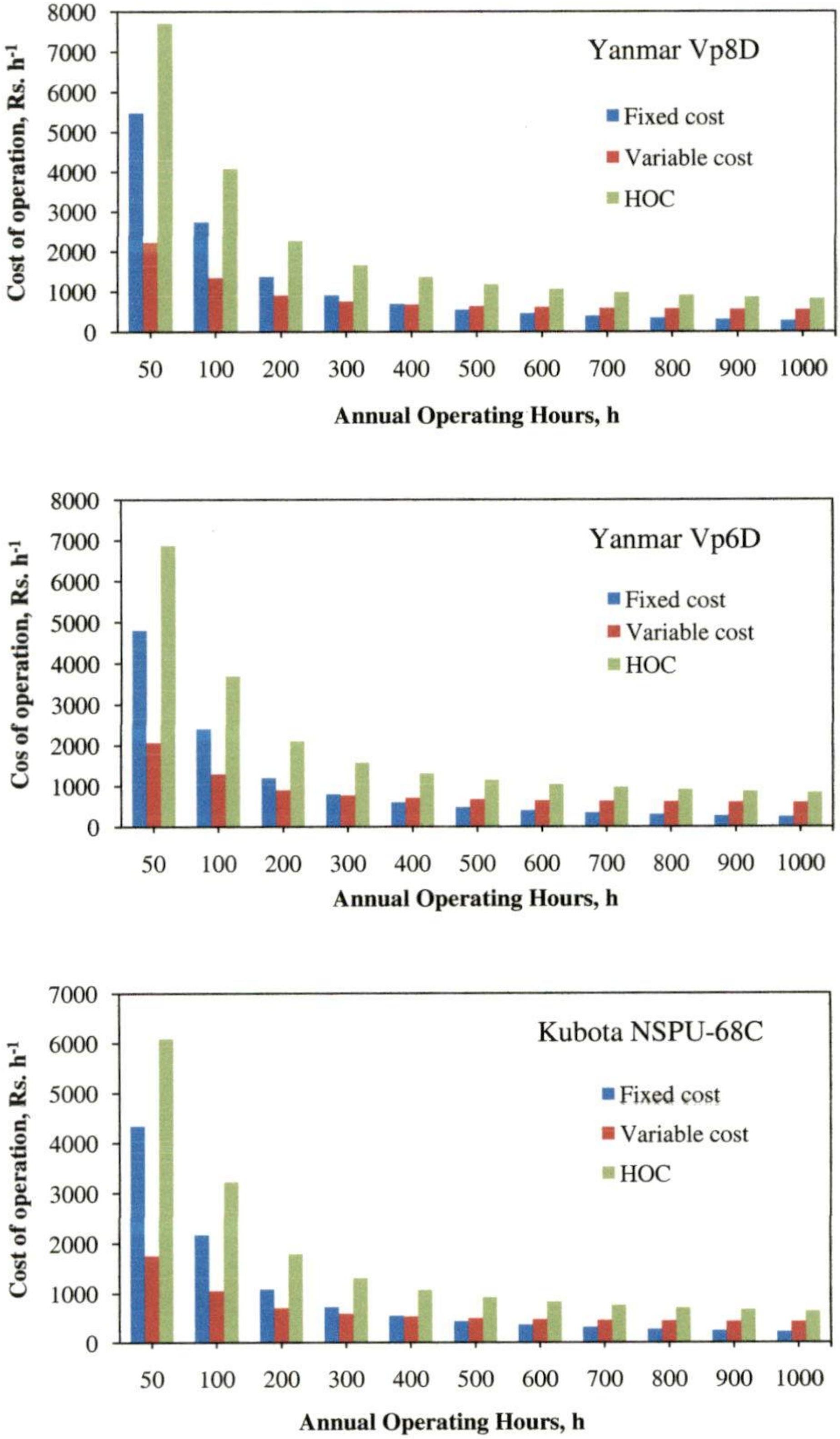

Figure 4.1 Components of hourly operational cost of different transplanters

Hourly operational costs of TR_1, TR_2 and TR_3 for AOH of 50 to 1000 are plotted in Figure 4.2. In general, the hourly operational costs were highest for TR_1 followed by TR_2 and TR_3 mostly due to the influence of the fixed cost factor, except at considerably high AOH beyond 800 h.

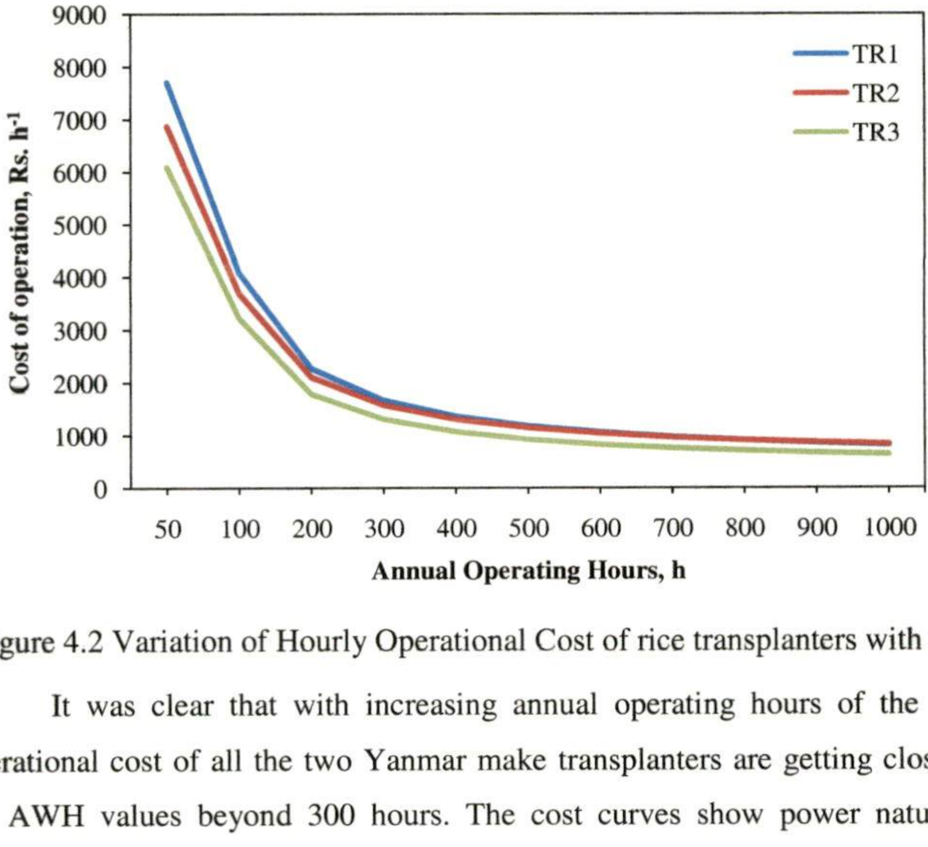

Figure 4.2 Variation of Hourly Operational Cost of rice transplanters with AOH

It was clear that with increasing annual operating hours of the hourly operational cost of all the two Yanmar make transplanters are getting closer, i.e. for AWH values beyond 300 hours. The cost curves show power nature and become flattened beyond 400 hours, respectively in the case of TR_1 and TR_2 and TR_3.

The relationships could be described by the following equations:

$HOC\ (TR_1) = 7088\ (AOH)^{-0.95}\ (R^2= 0.982)$

$HOC\ (TR_2) = 6218\ (AOH)^{-0.89}\ (R^2= 0.978)$

$HOC\ (TR_3) = 5615\ (AOH^{)\ -0.96}\ (R^2= 0.982)$

4.1.5 Unit Area Operational Cost of Rice Transplanters

In group mechanization system, as the machines are generally owned by co-operatives or similar organizations of farmers, the unit area operating cost is more pertinent as the charges are generally collected from individual farmers on the basis of area. UAOC is dependent on hourly operational costs and field capacities of the machines. TR_1 had the highest field capacity (0.4 ha h^{-1}) followed by TR_2 (0.38 ha h^{-1}) and TR_3 (0.33 ha h^{-1}). The variation of UAOC with annual working hours is shown in Figure 4.3.

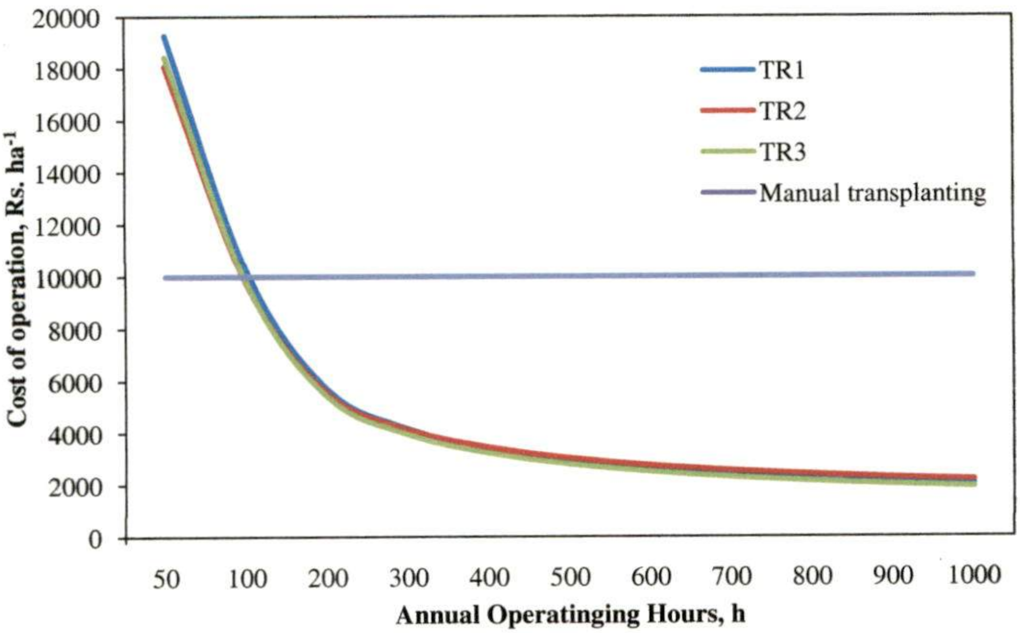

Figure 4.3 Variation in Unit Area Operating Cost of rice transplanters with AOH

The relationships of UAOC with the AOH showed that TR_1 had more UAOC than that of TR_2 and TR_3 up to 395 h. At 395 h UAOC of both TR_1 and TR_2 were equal. Beyond 395 h TR_2 had the maximum cost of operation among the three machines. Manual transplanting by labour contract required a cost of Rs. 10000 per ha. So using transplanters is economical than manual transplanting whenever the AWH is more than 102 h. The cost curves show power nature and become flattened beyond 300 h in the case of all the three transplanters.

The relationships could be described by the following equations:

$UAOC (TR_1) = 17722 (AOH)^{-0.95} (R^2 = 0.982)$

$UAOC (TR_2) = 16364 (AOH)^{-0.89} (R^2 = 0.978)$

$UAOC (TR_3) = 17015 (AOH)^{-0.96} (R^2 = 0.982)$

From Figure 4.3 it was evident that the probable AOH is an important criterion in selecting a transplanter, especially when its operation is confined to a specific *padasekharam*. The probable AOH in the *padasekharams* of the zone was found to be 300 hours in the survey, for which the UAOCs were Rs. 4,171/-, Rs. 4,143/- and Rs. 3,959/- per hectare for TR_1, TR_2 and TR_3, respectively. This is significantly lower than the manual transplanting cost. A similar study with different types of transplanters was done by Regina and James (2012) and they found out a similar trend in the variation of various economic parameters.

4.2 DEVELOPMENT OF TRANSPORT WHEEL FOR FOUR WHEELED RICE TRANSPLANTER

4.2.1 Selection of Pneumatic Transport Wheels

The dimensions of lugged wheel of the transplanter (Kubota NSPU-68C) provided by the company was as shown in Table 4.4.

Table 4.4 Dimensions of lugged wheel of transplanter

Wheel parameters		Dimensions
Front Wheels	Diameter	650 mm
	Width	100 mm
	Wheel track	1.20 m
Rear wheels	Diameter	900 mm
	Width	160 mm (at lugs), 30 mm (ring portion)
	Wheel track	1.20 m

It was observed that rubber tyres for pneumatic wheels corresponding to these dimensions were not available. Hence the nearest tyre sizes available in the market were selected and their dimensions were adopted (Table 4.5).

Table 4.5 Dimensions of the selected pneumatic wheels

Wheel parameters		Dimensions
Front Wheels	Diameter	680 mm
	Width	100 mm
	Wheel track	1.29 m
Rear wheels	Diameter	720 mm
	Width	130 mm
	Wheel track	1.37 m

The pertinent dimensions of the newly selected transport wheel system were estimated. The important parameter among them was the ground clearance of the transplanter at the front and the rear. The lower most part of the transplanter was the float of the seedling unit. The clearance from float was measured and it was found that the selected wheel size is appropriate for providing required clearance at the rear.

Another important parameter considered was the steerability of the transplanter when the front wheel diameter is changed. There was only an increase of 30 mm for the front wheel and hence no such problem was likely.

4.2.2 Conversion of 4-Wheel Drive Transmission to 2-Wheel Drive

As the rice transplanter was 4- wheel drive, the power was transmitted to all the four wheels. Once the drive wheel diameters were changed, the linear speed of the rear wheels could not match with that of the front wheels, if the same ratio is not maintained. The change in rpm ratio is shown in Table 4.6.

Table 4.6 rpm ratio of wheels of transplanter

Type of wheel	Number of rotations (N meters)		rpm ratio
	rear wheel	front wheel	
Lugged wheel provided by the manufacturer	N/2.83	N/2.04	1.385
Pneumatic wheels selected	N/2.26	N/2.14	1.06

The rpm ratio varied if the selected pneumatic wheels were fitted when the transmission is four wheel drive. Hence in order to avoid slippage due to differential peripheral velocity, the front wheels were disengaged from engine power by providing freely rotating wheel hubs. Four-wheel drive transmission was not essential for road transport. Hence it was decided to have rear wheel drive in the transportation mode by making the front wheels free.

4.2.2.1 Attachments for the transport wheel system

For converting the four-wheel drive to two-wheel drive, a bearing assembly was provided within the front wheel hub. By fitting these hubs the front wheels could be rotated freely, as no power was transmitted to them. Thus, the power from the engine was transmitted only to the rear wheels of the transplanter.

Based on design considerations, drawings of the attachments for front and rear wheels were developed using CAD software (Figure 4.4 and Figure 4.5).

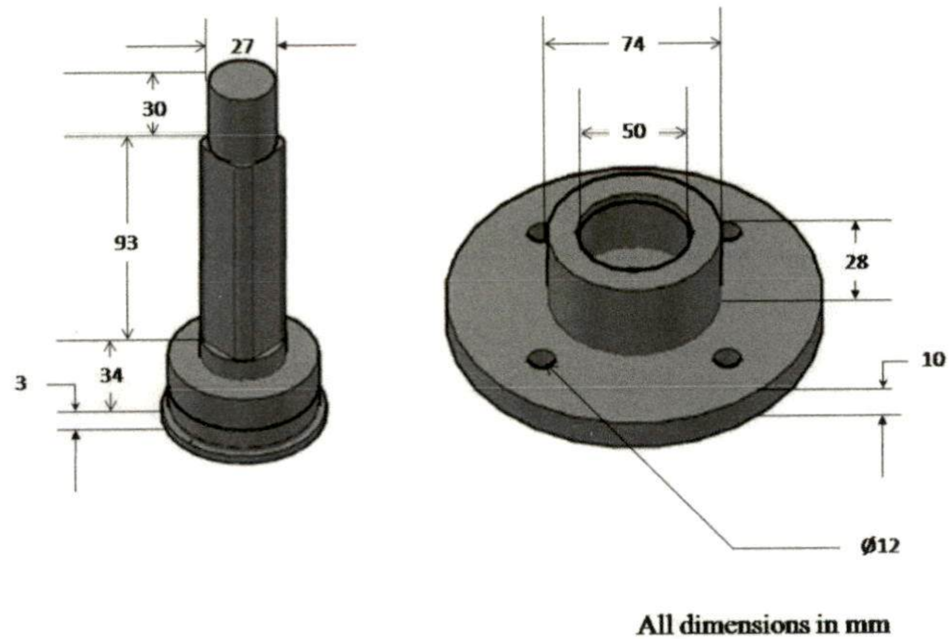

Figure 4.4 Attachments for front wheel hub

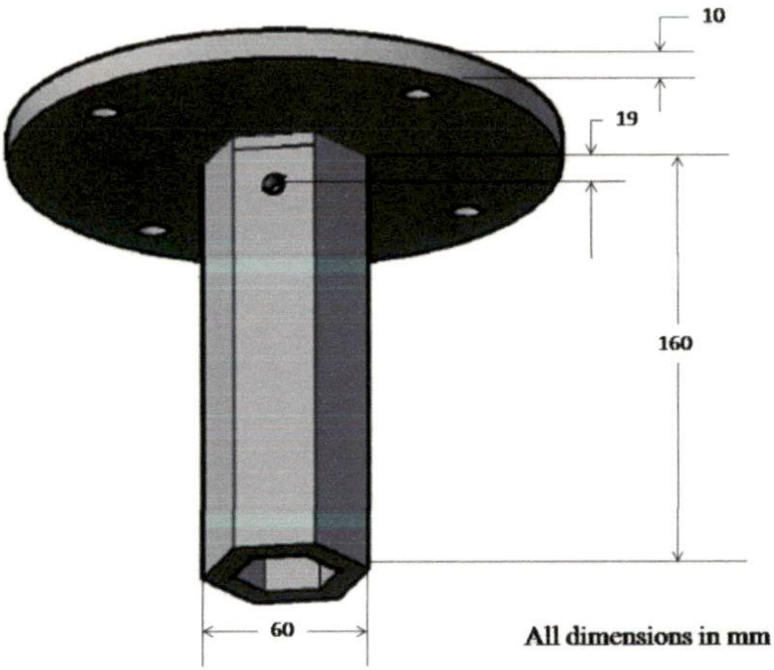

Figure 4.5 Attachment for rear wheel hub

Hubs fabricated for both front and back wheels are shown in Figure 4.6 and Figure 4.7.

Figure 4.6 Fabricated rear wheel hub attachment

Figure 4.7 Fabricated front wheel hub attachment

4.2.3 Performance of the New Transport Wheels

The transplanter fitted with pneumatic wheels is shown in Figure 4.8. Wheel base of the transplanter was originally 1.5 m and there was no change after fitting the pneumatic wheels. The presence of hydraulic shock absorbers provided enough space for accommodating the bigger front wheel. The wheel track which was originally 1.24 m slightly increased to 1.34 m. Even though the front wheel diameter was slightly increased (30 mm) no hindrance was found during its rotation. The steerability was also not affected.

The back wheels were replaced with a pneumatic tyre having lesser diameter of 720 mm and width of 130 mm. For transport purposes the seedling tray was kept in highest position from the ground and it gave a clearance of 300 mm up to the float of the planting mechanism. It was found to be comfortable with this wheel. There was enough clearance and no difficulties were found when the existing lugged wheels were replaced with pneumatic wheels.

Figure 4.8 Transplanter with pneumatic wheels

4.2.3.1 Speed of travel

A chance for change in speed of the transplanter was observed when the wheels were replaced with pneumatic wheels. It was observed that the transplanter with lugged wheel had on-road speeds ranging from 1.39 to 11.45 km h^{-1}. Transplanter with pneumatic wheels had an on-road speed varying from 1.14 to 9.88 km h^{-1}. Results showed that the speed had been slightly reduced from that of the lugged wheels. Thus the objective of replacing lugged wheels on road to protect it from damage was achieved.

4.2.3.2 Stability of the transplanter with newly fitted transport wheels

The centre of gravity of the transplanter with lugged wheels was located at 30.1 cm ahead of rear axle and 24.9 cm above the ground. In the case of transplanter fitted with pneumatic wheels, the centre of gravity was located at 40.6 cm ahead of the rear axle and 27.6 cm above the ground. From this it is clear that the centre of gravity of the transplanter is lying at below the transplanter.

4.2.4 Stopping Distance

Trials to assess the stopping distance required when the transplanter is fitted with pneumatic wheels revealed that at maximum speed the machine stopped at a distance of 1.16 m away from the point of breaking. At lower speeds, it stopped at the point where brake is applied. So care should be taken while applying brake at maximum speed. The operator needs to forecast the stopping distance of 1.2 m for the safe operation of the transplanter during on road transport. Otherwise chances for occurrence of accidents are more unless an improved braking system is provided.

4.3 DEVELOPMENT OF APPLICATOR ATTACHMENT

4.3.1 Components of Applicator

Based on design considerations the following components were selected for the fabrication of applicator attachment.

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a. Tank

A cylindrical plastic container of 50 litres capacity was selected as the tank for storing liquid formulations (bio-fungicides or micronutrients). It was fixed at the rear side platform of the transplanter. It had an opening at the top for filling. The inlet pipe to the pump was also taken out through this opening.

b. Pump

A battery operated 12V positive displacement diaphragm pump (Figure 4.9) was used for pumping the liquid formulations. It comprised of a combination of the reciprocating action of a teflon diaphragm with suitable valves on either side of the diaphragm to pump the fluid. This pump delivered a definite volume of spraying liquid in each stroke.

Figure 4.9 Battery operated 12 V pump

c. Hose

The hoses were made of low density poly ethylene (LDPE). Hoses of 12 mm diameter were used for this applicator for carrying spray fluid from the tank to the suction side of the pump as well as for the passage of pressurised spray fluid from the delivery side of the pump to the spray boom.

d. Spray boom with nozzles

Spray boom had five nozzles spaced at an equal distance of 35 cm. The spray boom was fitted just above the seedling tray of the transplanter. The adjacent nozzles were interconnected by Tee-joints. The pressurised liquid entered at one end of the boom and could be passed on to the nozzles.

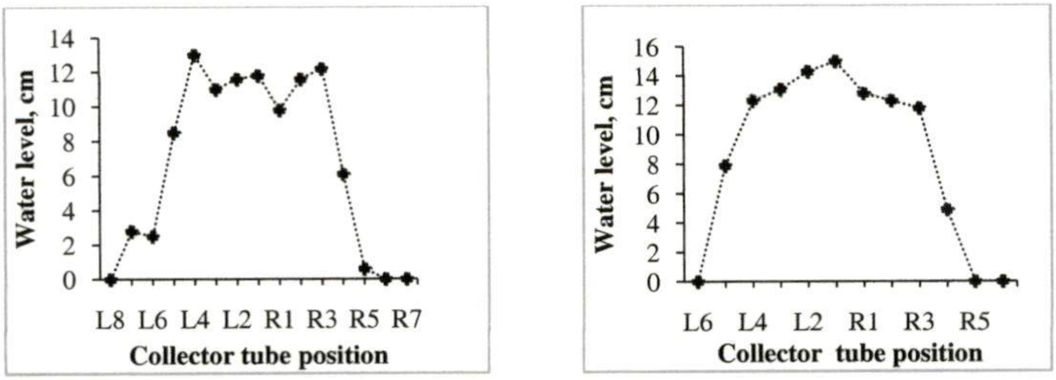
e. Nozzles

Nozzles used for this study were solid cone nozzles marketed by Agrimart.

4.3.2 Nozzle Selection

The nozzles were selected based on the patternator readings. The patternator readings of each of the nozzles and their spray patterns are shown in Appendix VII. The graphical representation of both solid cone and flat fan nozzles are shown Figure 4.10 (a) and (b) and Figure 4.11 (a) and (b).

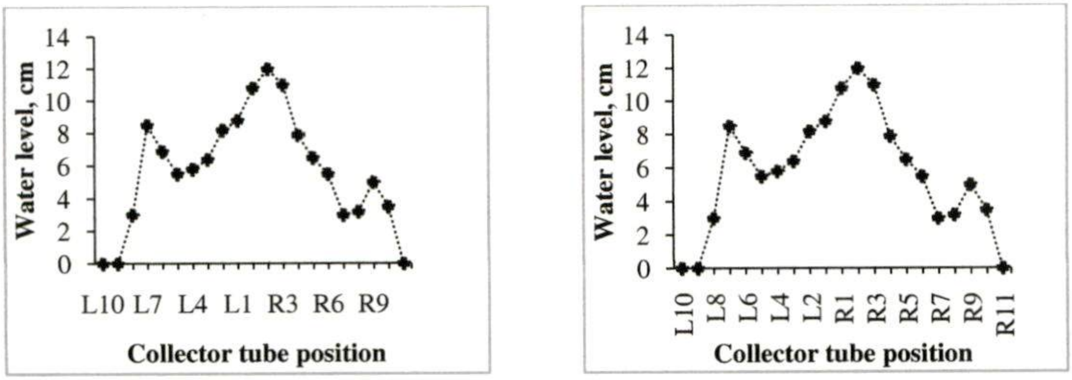
The L1,L2, etc. up to L8 represents the collector tubes arranged on the left side of the nozzle whereas R1, R2, etc up to R8 means collector tubes on the right side of the nozzle. Based on these values a graph was plotted to analyse the spray pattern of the nozzle. The spray patterns obtained for the two solid cone nozzles are shown in Figure 4.10 (a) and (b).



(a) (b)

Figure 4.10 Spray patterns obtained for the solid cone nozzles

The spray patterns of two flat fan nozzles of same make are shown in Figure 4.11 (a) and (b).



(a) (b)

Figure 4.11 Spray patterns obtained for the flat fan nozzles

From the spray patterns it was clear that solid cone nozzle could give a more uniform spray than flat fan nozzle. The flat fan nozzles showed an irregular pattern (Figure 4.12). A nozzle with lesser fluctuations in spray uniformity was required. Solid cone type nozzles had more uniform pattern at the required overlap. A graphical representation is shown in Figure 4.13.

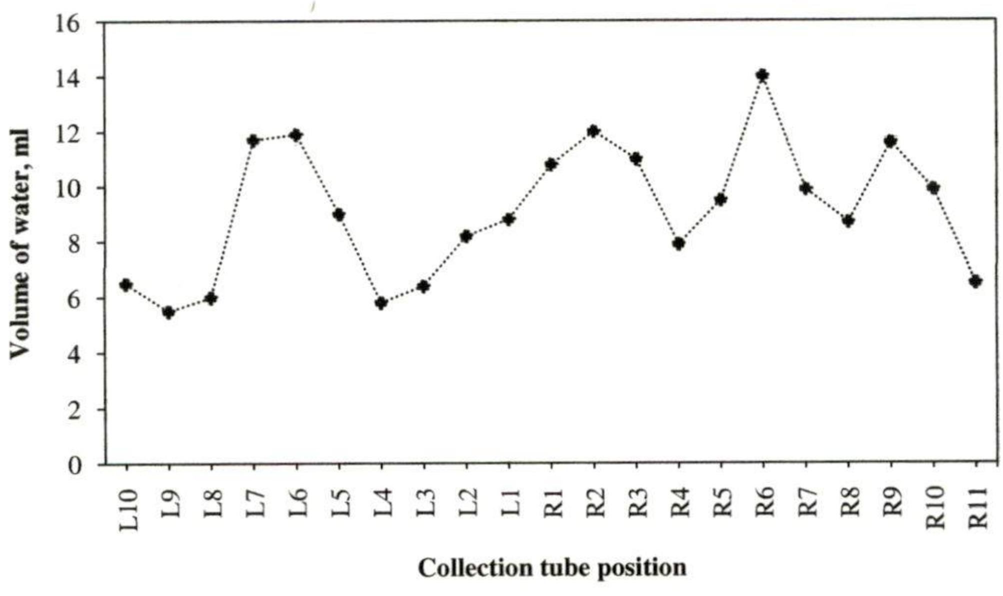


Figure 4.12 Spray pattern of flat fan nozzles at an overlap of 14 cm

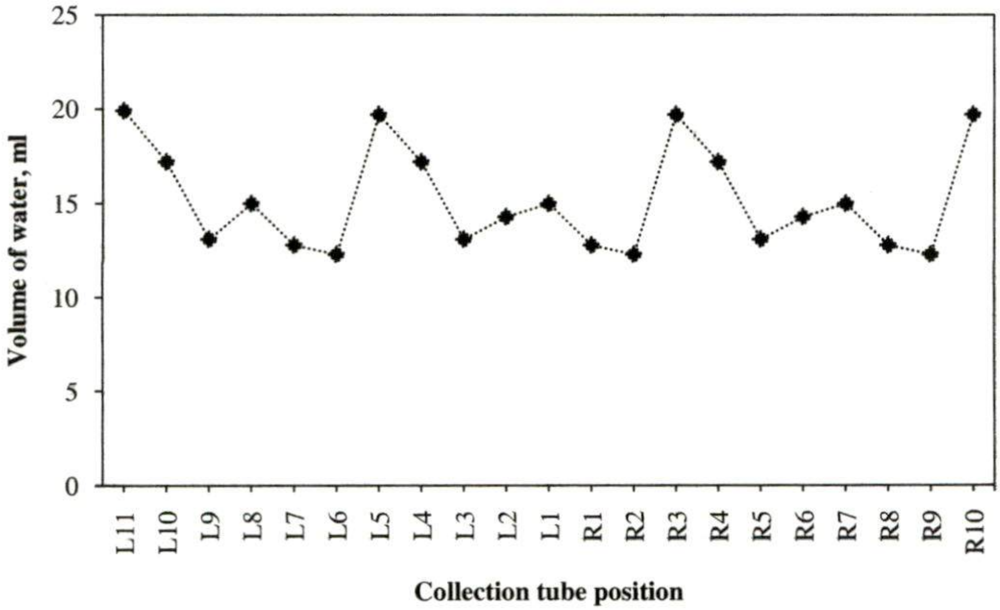


Figure 4.13 Spray pattern of solid cone nozzles at an overlap of 14 cm

The overlapping was done such that the target spray area received equal quantity of spray. Here the area to be sprayed was 180 cm i.e., the width of the seedling tray of 6-row transplanter. The spray width of a solid cone nozzle is 35 cm. The arrangement of nozzles on the applicator is shown in the Figure 4.14 and Figure 4.15.

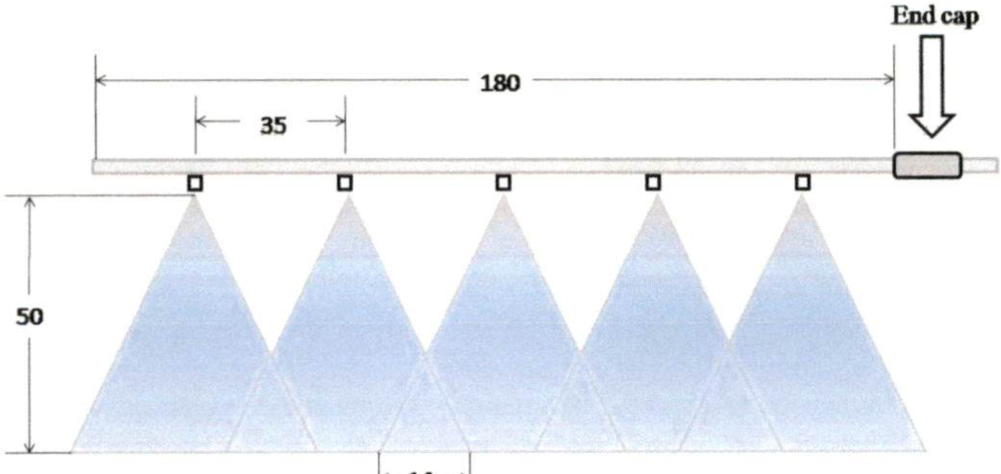


Figure 4.14 Arrangement of nozzles on the applicator

Figure 4.15 Applicator attachment fitted on the transplanter

The five nozzles were located on the spray boom such that the overlapping of spray span was 14 cm. The end nozzles were fixed on the boom so as to have a spacing of 23.5 cm from the edge of the seedling tray. This arrangement could ensure almost uniform spray over the entire span.

4.3.3 Pressure

The pressure of the spray fluid was measured using a bourdon pressure gauge and was 620 kPa.

4.3.4 Droplet Size

The size of the droplets analysed using the computer software, 'Image-J-2016, revealed that that the droplet size ranged from 200-300 microns (Figure 4.16).

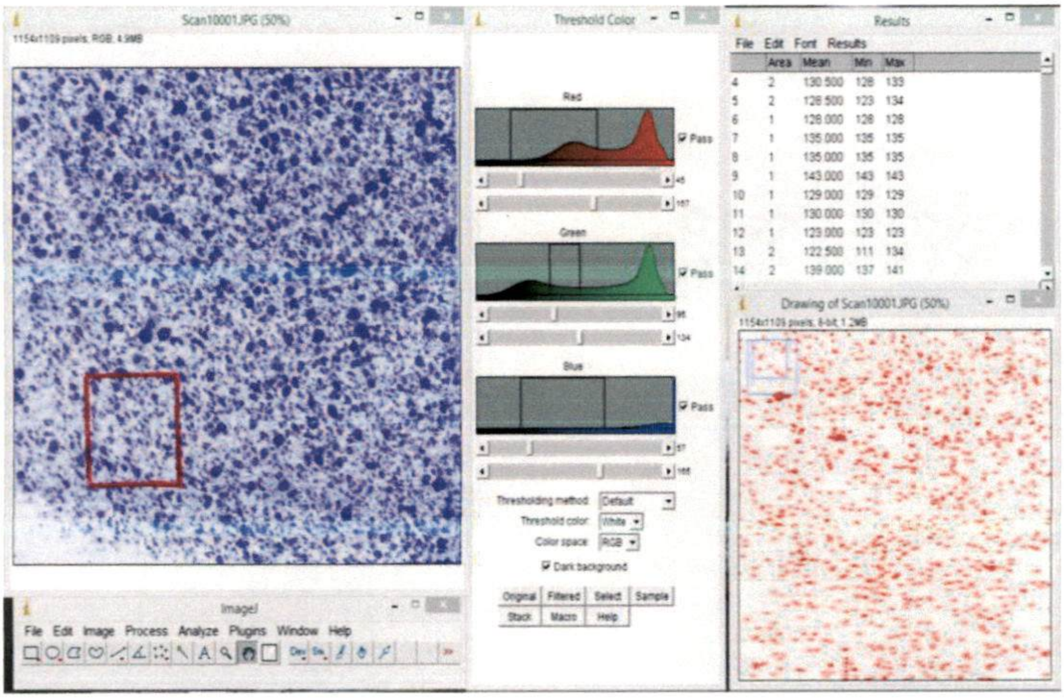


Figure 4.16 Droplet size analysis

4.3.5 Discharge

Discharge through the pump, spray applicator and each of the nozzles were measured separately. Discharge through spray applicator and each nozzle were estimated and shown in Table 4.7.

Table 4.7 Discharge through nozzles

Number of nozzles	Discharge (l min^{-1})
Total for 5 nozzles	1.890
Nozzle 1	0.390
Nozzle 2	0.407
Nozzle 3	0.417
Nozzle 4	0.382
Nozzle 5	0.385

The discharge of the pump without spray boom attached was 2.29 l min^{-1}. The total discharge through five nozzles of the spray applicator was found to be 1.89 l min^{-1}. The mean discharge through each nozzle was 0.396 l min^{-1}.

4.3.6 Rate of Application at Rated Speeds

Transplanting was done at different operating speeds. i.e. in different gears, and the rate of application of the spray fluid on unit area was estimated. The rate of application at different speeds was shown in the Table 4.8.

Table 4.8 Rate of application at different speeds

Gear	Area of mat nursery transplanted per unit time ($m^2\ min^{-1}$)	Volume of spray fluid applied on unit area of mat nursery (litre m^{-2})
1	0.213	8.88
2	0.221	8.54
3	0.227	8.32
4	0.229	8.24
5	0.234	8.08

For transplanting operation 3rd gear was most commonly used and the rate of application of the spray fluid on the mat nursery was estimated to be 8.32 l m^{-2}. With increase in speed, the rate of application of the fluid decreased and vice versa. Even if the speed is varied when the gears are switched between 3rd and 4th, there was not much variation in spray fluid (0.08 l min^{-1}).

4.3.7 Bio-fungicide (Pseudomonas) Application

Pseudomonas was sprayed on the mat nursery at the time of transplanting using the attachment. The plant height was monitored on the 30th and 90th day after transplanting. The average change in plant heights in all plots were pseudomonas applied is shown in the Table 4.9.

Table 4.9 Mean Plant heights in different plots treated with pseudomonas

Plot No.	30th Day		90th Day	
	Check plot	Treatment plot	Check plot	Treatment plot
1	37.8	41.2	83.2	91.4
2	37.2	42.4	84.4	85.6
3	39.6	40.8	84	83.6
Mean	**38.2**	**41.46**	**83.86**	**86.86**

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From Table 4.9, it was clear that the plants which received pseudomonas had a marginal increase in growth compared to the check plots, indicating a favourable effect of pseudomonas application. The plots were monitored throughout the crop period for fungal attack and no such attack was observed either in the treated plots or the check plots.

4.3.8 Micronutrient Application

The micronutrient which is applied as foliar application will affect the entire plant growth. The pre-harvest and post-harvest parameters considered under this study are presented in the Appendix VIII. The average plant height of both check plot and treatment plot at 30^{th} and 90^{th} days after transplanting are shown in Table 4.10.

Table 4.10 Mean plant heights in different plots treated with micronutrients

Plot No.	30^{th} Day		90^{th} Day	
	Check plot	Treatment plot	Check plot	Treatment plot
1	43.8	45.6	94.2	90
2	40.4	46.6	85.4	110.2
3	46.8	46.6	100	100.2
4	34.6	37.4	88.6	119.4
5	37.6	39.8	82.4	118.8
6	39.6	40.2	79.6	117
7	35.4	34.8	84.4	114.4
8	36.8	38.2	88	116.8
Mean	**39.37**	**41.15**	**87.82**	**110.85**

Other growth indicators considered were Number of hills m^{-2}, Number of tillers per hill, Productive tillers m^{-2}, Unproductive tillers m^{-2}, Number of panicles per hill, Grains per panicle, Paddy yield m^{-2} and 100 grain weight. Observations for each plant growth parameters are given in Appendix VIII. These parameters were analysed through Paired T-test in order to determine the significance of the application of micro nutrient mix, '*Sampoorna* KAU multimix'.

From the Paired T- test, it was found that the plants treated with *Sampoorna* showed significantly higher values for all the growth parameters other than unproductive tillers m^{-2} compared with the untreated plots (Appendix IX). Histograms plotted for different plant growth parameters are depicted in Figure 4.17 to 4.25.

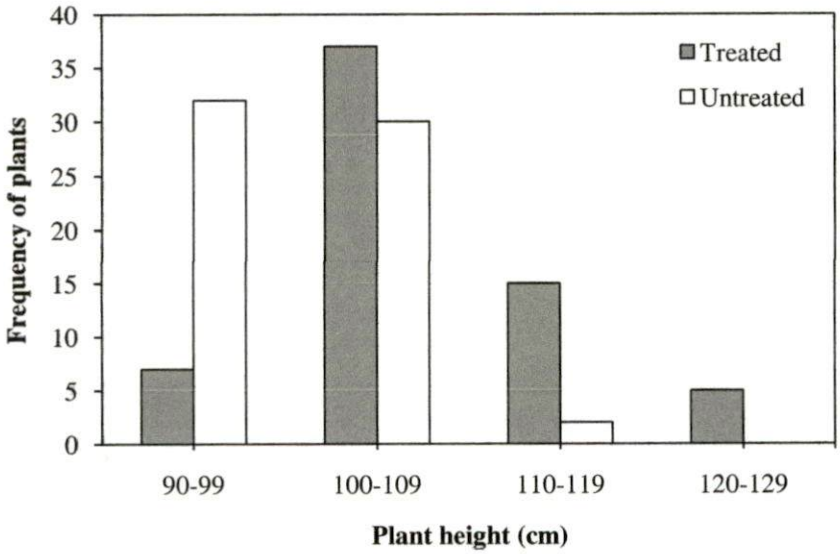

Figure 4.17 Frequency distribution of plant heights

The frequency distribution of plant heights depicted in Figure 4.17 indicates that more number of *Sampoorna* treated plants attained the height range of 120 - 129 cm whereas maximum number of untreated plants fell into the height class of 90-99 cm. This is a clear sign that the plants treated with *Sampoorna* attained more heights compared to untreated plants. A considerable number of micronutrient applied plants were seen in the maximum plant height range of 120 - 129 cm; where as those without treatment could not be seen in that range. The tallest untreated plants could only reach the height range of 110 - 119 cm. The average plant heights of the treated and untreated plants were 98 cm and 91 cm, respectively.

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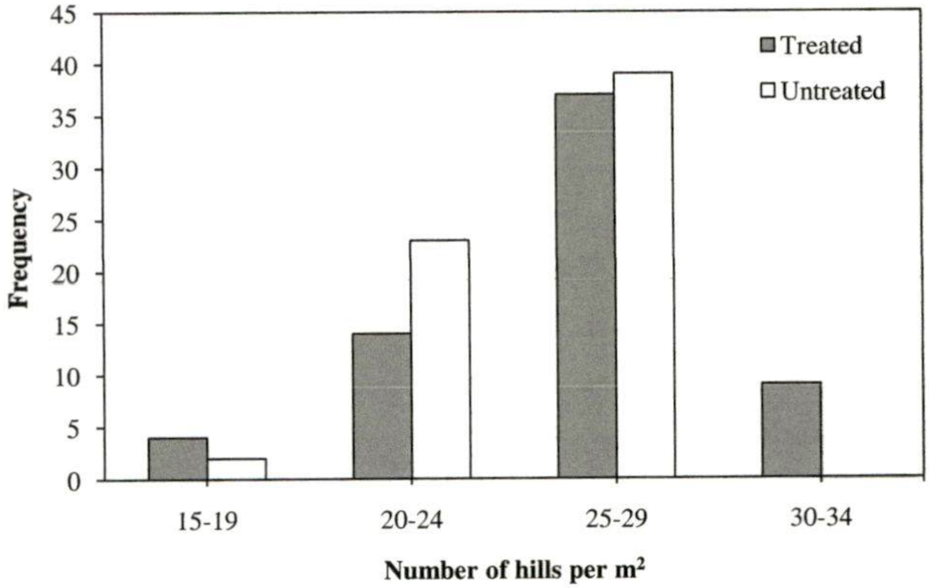

Figure 4.18 Frequency distribution of number of hills per m^2

The results depicted in Figure 4.18 shows that the plots treated with *Sampoorna* have more number of hills per m^2 than untreated plants. The micronutrient applied plants had maximum number of hills per m^2 within 25-29 which was same for untreated plants. The average number of hills per m^2 of the treated and untreated plots was 22 and 20 respectively.

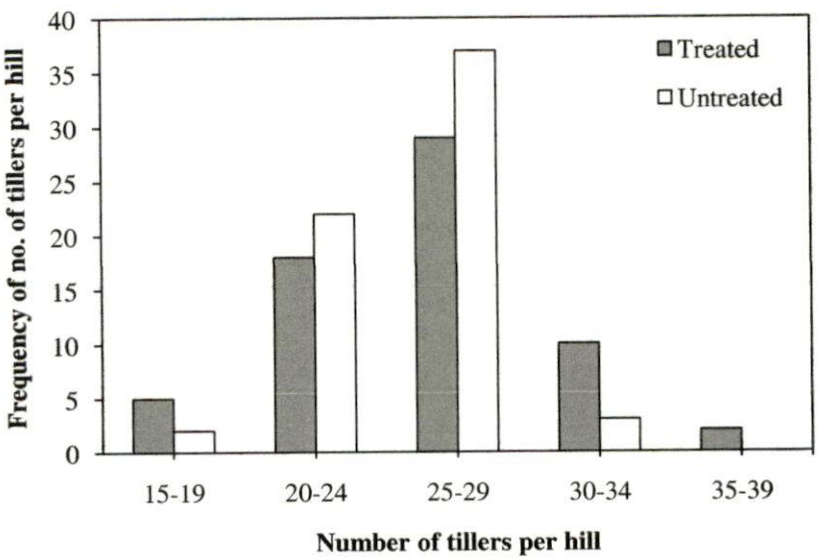

Figure 4.19 Frequency distribution of number of tillers per hill

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From Figure 4.19 it was clear that treated plants produced more number of tillers per hill than that of untreated plants. Maximum number plants, both treated and untreated were in the range of 25-29 tillers per hill. The treated plants only could find their position in the maximum tiller range of 30-34. The average number of tillers per hill of treated and untreated plants was 17 and 10, respectively.

The results obtained from Figure 4.20 showed that the plants treated with *Sampoorna* produced more productive tillers m^{-2} than untreated plants. The micronutrient treated plants had maximum number of productive tillers m^{-2} with frequency 50. Whereas untreated plants had a maximum 300 productive tillers m^{-2} with frequency of around 30. The average number of productive tillers m^{-2} for treated and untreated plants were 268 and 254 respectively.

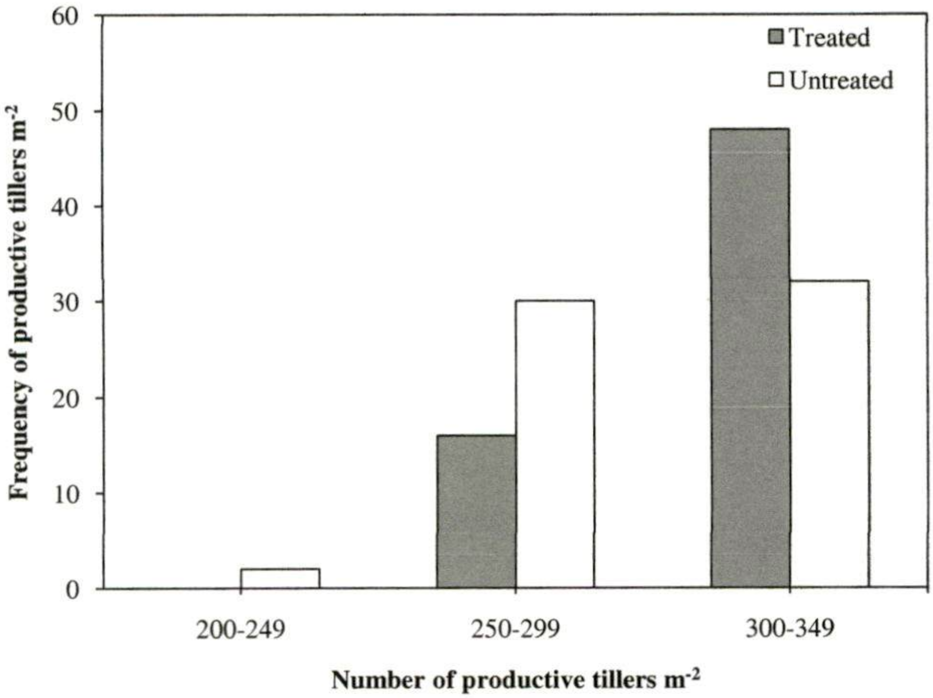

Figure 4.20 Frequency distribution of number of productive tillers m^{-2}

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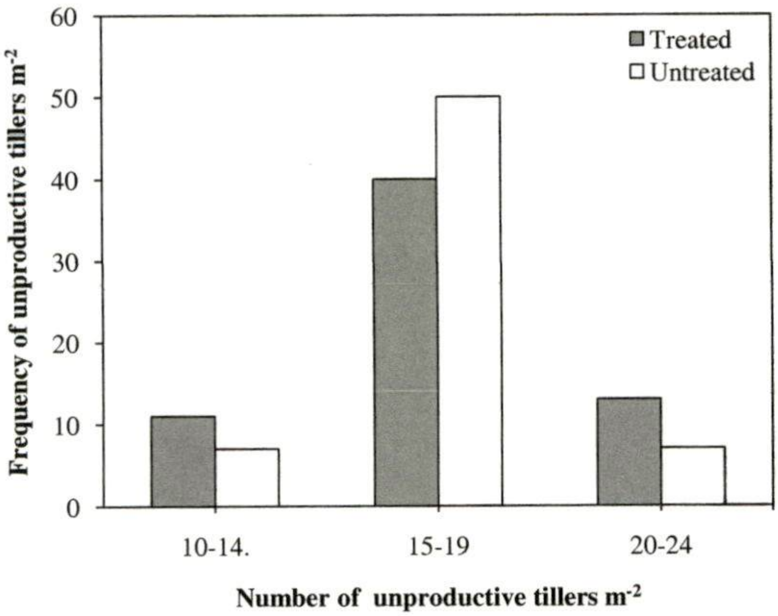

Figure 4.21 Frequency distribution of number of unproductive tillers m^{-2}

From the graph plotted (Figure 4.21) the plants treated with *Sampoorna* micronutrient showed more number of unproductive tillers m^{-2} than that of untreated plants. The treated plants had maximum number of unproductive tillers m^{-2} of 20 to 24 with frequency of 15 whereas that of untreated plants had 20 to 24 unproductive tillers m^{-2} with frequency of 8. The average unproductive tillers m^{-2} for treated and untreated plants was 13.

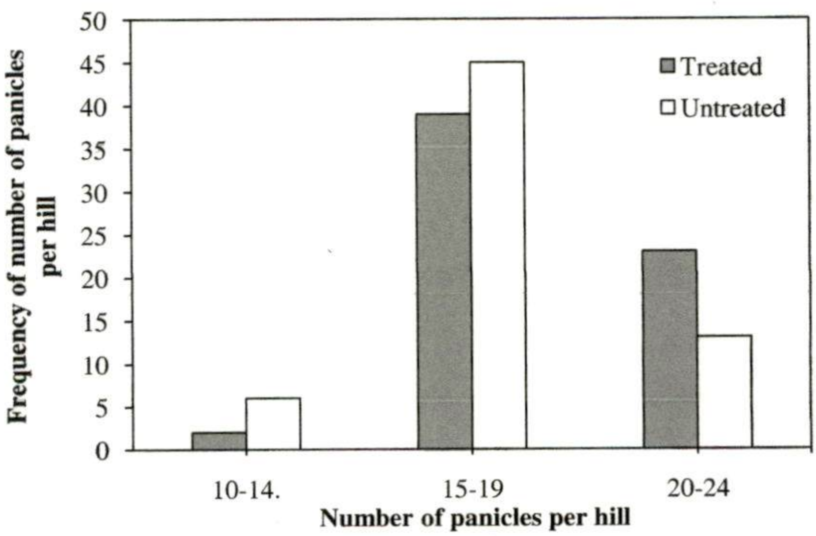

Figure 4.22 Frequency distribution of number of panicles per hill

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Figure 4.22 depicts the frequency of treated and untreated plants in the three different ranges of per hill panicles. More number of *Sampoorna* treated plants (frequency 25) could be observed in the maximum panicle range of 20-24 whereas the frequency of untreated plants in this range was only 15. However, the average number of panicles per hill for the treated and untreated plants did not show much variation and were 14 and 13 respectively.

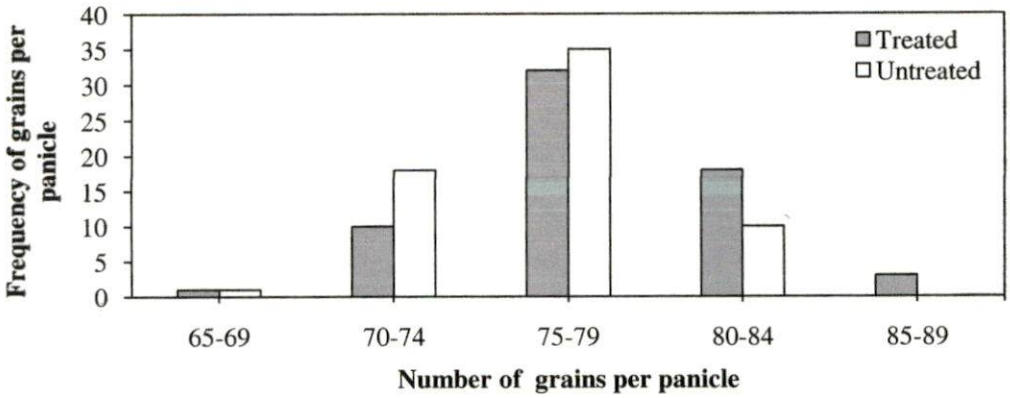

Figure 4.23 Frequency distribution of number of grains per panicle

Figure 4.23 reveals that the treated plants had more grains per panicle than that of untreated plants. The 85 - 89 grains per panicle class had only treated plants. This trend is also observed in the range 80-84 grains, where the frequency of treated plants is much higher than the untreated. The average grains per panicle for treated and untreated plants were not much different and found to be 74 and 72, respectively.

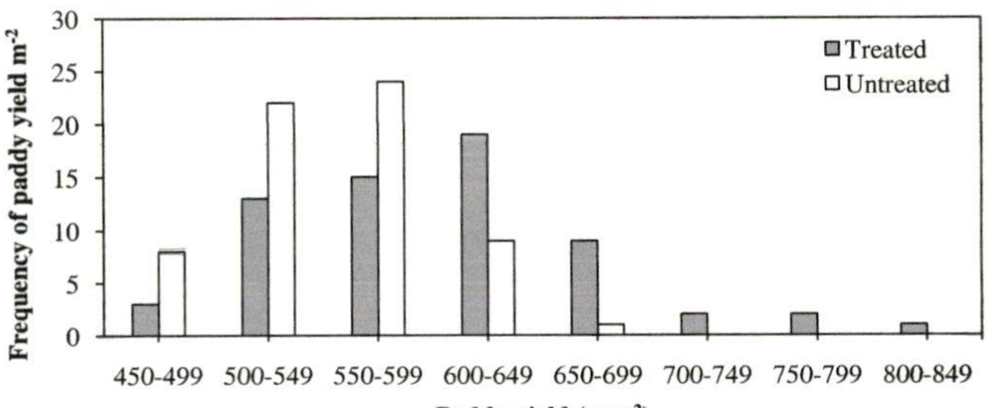

Figure 4.24 Frequency distribution of paddy yield m^{-2}

From Figure 4.24, it is evident that only the plots treated with *Sampoorna* could get into the high paddy yield classes i.e., above 700 g m^{-2}. The dominance of Sampoorna treated plots could be well established from the frequency distribution shown in Figure. 4.24. The average paddy yield per m in the treated and untreated plots was 554 and 504 g $m^{-2,}$ respectively.

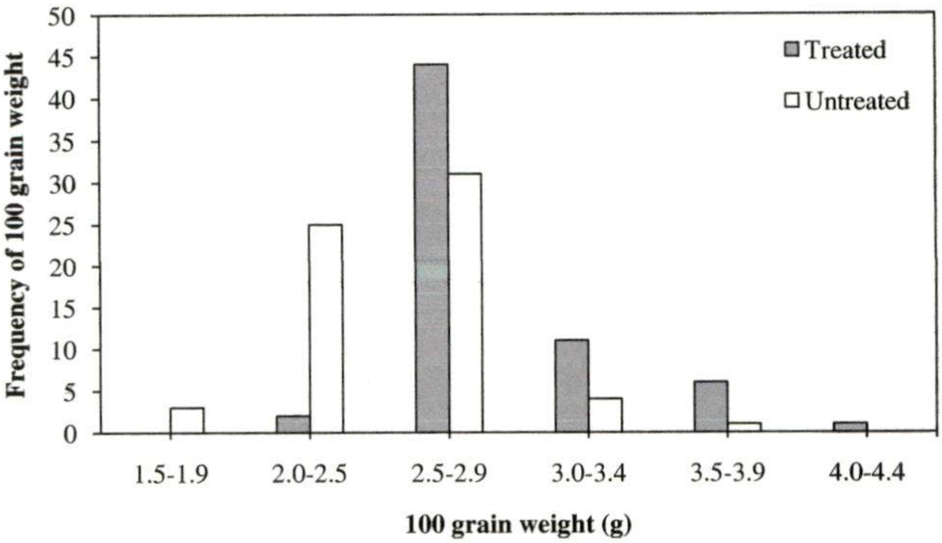

Figure 4.25 Frequency distribution of hundred grain weight

Figure 4.25, illustrates that the treated plots had higher 100 grain weight than untreated. The superiority of treated plots in 100 grain weight is spectacular from the frequencies sown in the figure. Treated and untreated plots had an average 100 grain weight of 2.4 g and 2 g, respectively.

The above results on various yield attributes clearly established the advantage of micro nutrient application as well as its effectiveness in spraying it on the mat nursery immediately before transplanting. Zayed *et al.* (2011) and Esfahani *et al.* (2014) in their studies reported that the foliar application of micronutrients significantly improved growth of rice plants. Plant height and panicle length were significantly higher when rice plant received micronutrient compared to the control. They opined that grain yield, straw yield, harvest index and other yield components like panicle numbers, panicle weight, filled grains per panicle and 1000-grain weight significantly increased by application of micronutrients.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Rice is the most important cereal food crop of the world providing major source of the food energy for more than half of the human population. Paddy is grown traditionally by manual transplanting. But due to the drudgery and increased labour cost mechanical transplanting of paddy is getting popular. Different types and makes of rice transplanters are currently used and the four wheel riding type machine is getting popular as it can ensure speedy operation so as to meet the challenges imposed by climate change. But these machines are costly and hence an agro-economic analysis of their use is required for their proper management. Another handicap in the use of these machines is that they need to be transported in another vehicle even to nearby areas, which results in increased cost of operation. A suitable transport wheel system can address this issue. The application of bio fungicides like pseudomonas is very much relevant in organic agriculture and the recommendation for its foliar application is not often followed by farmers due to the drudgery and labour requirement. Kerala Agricultural University is also recommending the use of micro nutrients in rice cultivation and has come out with "*Sampoorna*- KAU multi mix" for foliar application. Hence an effort was done with the objectives of agro-economic analysis of four-wheel riding type rice transplanters and development of a transport wheel system. Another major objective was the development of an applicator attachment for spraying liquid formulations of bio-fungicides and micronutrients on the mat nursery loaded in the seedling tray of the machine, immediately before transplanting.

For conducting agro economical analysis, the onset of transplanting was determined using weekly normal rainfall in standard meteorological weeks. The paddy varieties considered in this study were *Uma, Jyothi* and *Prathyasha*. Economic parameters of three makes of four-wheel riding type rice transplanters, viz. Yanmar Vp8D (TR_1), Yanmar Vp6D (TR_2) and Kubota NSPU-68C (TR_3) were analysed using standard methodologies. For developing transport wheel 86 system, the 6 – row Kubota transplanter (TR3) was selected. Wheel hub assemblies were fabricated based on the design considerations for fitting the pneumatic wheels of suitable size. The developed transport wheel system was evaluated for its ground speed, centre of gravity and stopping distance. An applicator attachment suitable for 6-row four-wheel riding type transplanters was developed for the application of bio-fungicides and micronutrients in consideration of the agronomic requirements. The effects of micronutrients and bio-fungicide application on various crop parameters were studied in the field.

From the agro economic analysis it was found that the annual fixed cost, annual variable cost and hourly operational cost were maximum for TR_1, followed by TR_2 and the TR_3 respectively. In group mechanisation system, as the machines are generally owned by co-operatives or similar organizations of farmers, the unit area operating cost (UAOC) is more relevant as the charges are generally collected on the basis of area. UAOC was dependent on hourly operational costs and field capacities of the machines.TR_1 has the highest field capacity (0.4 hah^{-1}) followed by TR_2 (0.38 ha h^{-1}) and TR_3 (0.33 ha h^{-1}). TR_1 had more UAOC than that of TR_2 and TR_3 up to the Annual Operating Hours (AOH) of 395 h. At 395 h UAOC of both TR_1 and TR_2 were equal. Beyond 395 h TR_2 had the maximum cost of operation among the three machines. Manual transplanting by labour contract required a cost of Rs. 10000 per ha. So using these transplanters is economical than manual transplanting whenever the AOH is more than 102 h.

The pneumatic wheels of 680 mm diameter and width of 100 mm was selected for front wheel. The front wheel and rear wheel tracks were 1.29 and 1.37 m, respectively. The rear wheels had a diameter of 720 mm with the tyre width of 130 mm. The maximum and minimum speeds of the transplanter fitted with the developed transport wheel system were 1.14 and 9.88 km h^{-1}. The stopping distance of transplanter with pneumatic wheels was 1.12 m at the maximum speed. Centre of gravity of transplanter with pneumatic wheels were located at 40.6 cm ahead of the rear axle and 27.6 cm above the ground.

The applicator attachment had a 12 V electrically operated diaphragm pump, LDPE pipes as conduit, solid cone nozzles fitted on a LDPE boom. The pressure developed by the pump was 620 kPa with a discharge of 1.89 l min^{-1}.The nozzles were selected based on the patternator studies. Five nozzles were placed at an equal distance of 35 cm on the boom of 1.8 m, with a spray span overlap of 14 cm. The droplet size was measured using bromide photo papers with pigmented spray solution and IMAGE-J image analyzing computer software. The droplet size at 50 cm height was in the range of 200 to 300 microns.

The field studies on effect of pseudomonas fluorescence application revealed the enhanced growth of rice plants. No fungal attack was observed in the plots which were treated with pseudomonas. The plants subjected to application of '*Sampoorna*- KAU mutimix' had increased plant height, more number of tillers per unit area, more productive tillers, more number of grains per panicle, higher paddy yield and increased 100 grain weight.

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Appendices

APPENDIX I

Onset of monsoon

Year	Date of onset of monsoon
2007	28 May
2008	31 May
2009	23 May
2010	31 May
2011	29 May
2012	5 June
2013	1 June
2014	6 June
2015	5 June
2016	8 June

(Source: IMD,2017)

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APPENDIX II

Standard meteorological week chart

Week No.	Dates	Week No.	Dates
1	01 Jan – 07 Jan	27	02 Jul –08 Jul
2	08 Jan – 14 Jan	28	09 Jul – 15 Jul
3	15 Jan – 21 Jan	29	16 Jul – 22 Jul
4	22 Jan – 28 Jan	30	23 Jul – 29 Jul
5	29 Jan – 04 Feb	31	30 Jul – 05 Aug
6	05 Feb – 11 Feb	32	06 Aug – 12 Aug
7	12 Feb – 18 Feb	33	13 Aug – 19 Aug
8	19 Feb – 25 Feb	34	20 Aug – 26 Aug
9*	26 Feb – 04 Mar	35	27 Aug – 02 Sep
10	05 Mar – 11 Mar	36	03 Sep – 09 Sep
11	12 Mar – 18 Mar	37	10 Sep – 16 Sep
12	19 Mar – 25 Mar	38	17 Sep – 23 Sep
13	26 Mar – 01 Apr	39	24 Sep – 30 Sep
14	02 Apr – 08 Apr	40	01 Oct – 07 Oct
15	09 Apr – 15 Apr	41	08 Oct – 14 Oct
16	16 Apr – 22 Apr	42	15 Oct – 21 Oct
17	23 Apr – 29 Apr	43	22 Oct – 28 Oct
18	30 Apr – 06 May	44	29 Oct – 04 Nov
19	07 May – 13 May	45	05 Nov – 11 Nov
20	14 May – 20 May	46	12 Nov – 18 Nov
21	21 May – 27 May	47	19 Nov – 25 Nov
22	28 May – 03 Jun	48	26 Nov – 02 Dec
23	04 Jun – 10 Jun	49	03 Dec – 09 Dec
24	11 Jun – 17 Jun	50	10 Dec – 16 Dec
25	18 Jun – 24 Jun	51	17 Dec – 23 Dec
26	25 Jun – 01 Jul	52**	24 Dec – 31 Dec

* Week No. 9 will be 8 days during leap year

** Week No. 52 will always have 8 days

APPENDIX III

Weekly normal rainfall of 13 AEUs in the central zone of Kerala

Table No. Weekly Normal Rainfall (mm) as per present climate													
Week No	AEU's in Palakkad District												
	5	6	9	10	11	12	13	14	15	18	19	22	23
1	0	0	0	0	0	0	0	0	0	5.1	2.8	0	0.3
2	0	0	5	0	1.7	0.1	0	1	0	2.3	1.2	0	0.5
3	0	0	6.8	0	0.4	0.5	0	0	0	7.5	3.6	0	0.1
4	0	0	0	0	0	0	5	0	0	4.5	2.1	0.5	0
5	0	0	0	0	1.6	0	0	0	0	8	4.5	0	0.3
6	0	0	0	0	1.8	0	16	0	0	10.7	6.1	0	2.8
7	0	0	0	0	1.6	0	0	0	0	4	1.5	0	0.3
8	0	0	8	0	0.9	12.2	0	22	15.4	10.8	3.8	0	7.2
9	26	0	9.2	0	1.5	11.6	0	13.4	25	20.7	9.7	3.5	4.4
10	8	0	4	0	1.9	18.4	0	41	8.4	22.9	11.7	0	2.4
11	0	0	0	0	4.5	2.6	46	0	0	16.5	5.5	16.5	5.7
12	0	0	6.2	0	12.3	10	0	4.2	5	28.1	8.8	0	4.5
13	0	0	0	0	5.3	0	24	0	0	36.6	25.6	0.1	9.9
14	0	0	3.2	1.2	18.2	15	67	35.2	16.4	28.4	20.2	3.2	13.7
15	0	48.6	42.8	22.4	22.1	64.8	97	9	14	20	14.1	0	13.9
16	58	0	6.2	0	21.6	49.3	32	12.2	22.8	40.1	29.6	0	17

17	0	0	29.6	0	33.7	116.5	24	8	8.2	30	19.7	15	12.4
18	0	45.6	141.8	1.2	19	198.3	57	83	64.4	22.6	14	26.9	22.8
19	14	196.8	143.6	201.5	45.4	130.6	27	162.2	112.4	23.2	17.5	0	15.9
20	81	0	0	0	33.1	84	155	0	1.4	17.9	8.5	50.7	21.9
21	138	0	0	25.3	48.1	2.4	39	4	6	19	15.4	27	17.1
22	585	18.8	13.8	127.7	113.6	9.4	22	35	18.8	40.6	26.9	291.9	28.6
23	40	152.2	37.2	86.7	167	64.6	46	78.4	37	19.7	13.1	97.1	36
24	17	280.2	18.2	185.2	193.3	67.9	257	44	52.8	26.4	17.4	75.5	79.1
25	353	97.2	58	124.3	199.6	100.6	12	122.2	349	18	15.8	218.8	85.9
26	281	81	22.4	29.2	173.3	48.4	37	72.4	149	27.6	19.8	256	75.2
27	124	28.6	24.8	14.5	176.9	37.9	90	37	62.4	21.7	14.3	245.1	96.4
28	269	232.2	42.2	246.5	174.1	100	207	97	446.4	24.9	13.9	137.6	76.7
29	120	151.8	20.8	93.3	184.2	82.1	38	102	279.6	26.3	22.2	195	82
30	111	158.6	34	244.1	159	43.5	66.6	81	236.2	49.8	36.5	320.4	114.9
31	86	180.6	94	339	135.2	165.9	145	135	394.8	37.8	31.6	212.4	85
32	114	153.4	33.6	140.4	107.1	69	52	48	157.6	33.5	23.6	85.1	52.9
33	321	8.4	13	11.6	77.8	78.2	109	27	115	55	38.3	198.3	42.1
34	0	276.8	137.2	137.7	77.3	354.4	0	194	169.2	58.5	42.4	50.7	41
35	8	175.4	142.4	185.2	74.8	156.8	0	179	333.6	74.2	45.7	0	43.3
36	22	88	64.2	61.4	69.5	74.9	20	88	124.4	53	39	0.7	38.4
37	157	24.2	0	6.3	76.1	54.2	20	19	142.2	65.6	44.6	0	25.6
38	127	5.2	7.2	0	51.5	2.5	12	7	24.8	65.8	39.1	0	22.9
39	72	45.4	85.6	70.8	53.7	115.1	9	85	147.8	69.9	42.9	0	26.5

40	93	13	52	47.5	68.1	97.3	100	39	32.4	65.7	43.1	143.3	29.7
41	87	83.6	47.2	83.7	101.4	21.7	248	16	83.8	50.5	31.6	119.6	34.2
42	39	120	142.6	136	74.3	143	81	145.2	98.6	39.1	21.5	54.9	47.7
43	13	95.8	45.8	30.8	66.2	35.9	20	128.2	158.2	30.2	19	8.4	32.3
44	22	17.6	83.8	58.9	54.8	77.9	134	88	128.2	37.8	25.6	21.5	46.3
45	17	0	0	2.1	51.6	49.6	220	5	21.2	33.5	21.7	6.8	41.6
46	8	94.8	84.2	10.3	37.4	71.6	19	52	25	36	23.4	0	18.7
47	150	4.6	31.6	6.2	25.8	25.3	14	24	4	16.5	9.5	0	12.4
48	0	0	30	0	10	7.8	3	43.2	0.8	11	5.3	25	5.2
49	0	0	1	0	7.9	0	4	0	1.6	7.5	3.8	2.3	5.1
50	0	21.2	34.4	21.5	8.3	16.9	0	23.2	18	9.5	4.8	6.9	6.7
51	0	0	5.2	0	7.8	4.2	0	7.2	0	7.8	4.4	24.4	2.3
52	0	0	19	0	2	2.8	0	6	38.4	1	0.3	0	1.1
TOTAL	3561	2899.6	1831.8	2752.5	3054.3	2895.7	2574.6	2423.2	4150.2	1493.3	967	2941.1	1508.9

APPENDIX IV

Duration of transplanting at various AEU's of Palakkad district

Crop combination for *Virippu* and *Mundankan* season	AEU's in Palakkad District															
	AEU 10		AEU 13		AEU 14		AEU 15		AEU 18		AEU 19		AEU 22		AEU 23	
	Virippu	*Mundakan*	*Virippu*	*Mundakan*	*Virippu*	*Mundakan*	*Virippu*	*Mundakan*	*Virippu*	*Mundakan*	*Virippu*	*Mundakan*	*Virippu*	*Mundakan*	*Virippu*	*Mundakan*
Uma - Uma	04 Jun - 08 Jul	20 Sep - 24 Oct	11 Jun - 24 Jun	27 Sep - 10 Oct	28 May - 08 Jul	13 Sep - 24 Oct	28 May - 17 Jun	13 Sep - 03 Oct	21 May - 29 Jul	06 Sep - 14 Nov	18 Jun - 29 Jul	04 Oct - 14 Nov	18 Jun - 29 Jul	04 Oct - 14 Nov	25 Jun - 29 Jul	11 Oct - 14 Nov
Uma - Jyothi	04 Jun - 08 Jul	20 Sep - 18 Nov	11 Jun - 24 Jun	27 Sep - 18 Nov	28 May - 08 Jul	13 Sep - 18 Nov	28 May - 17 Jun	13 Sep - 18 Nov	21 May - 05 Aug	06 Sep - 21 Nov	18 Jun - 05 Aug	04 Oct - 21 Nov	18 Jun - 05 Aug	04 Oct - 21 Nov	25 Jun - 05 Aug	11 Oct - 21 Nov
Uma - Prathyasha	04 Jun - 08 Jul	20 Sep - 02 Dec	11 Jun - 24 Jun	27 Sep - 02 Dec	28 May - 08 Jul	13 Sep - 02 Sep	28 May - 17 Jun	13 Sep - 02 Sep	21 May - 12 Aug	06 Sep - 18 Nov	18 Jun - 12 Aug	04 Oct - 28 Nov	18 Jun - 12 Aug	04 Oct - 28 Nov	25 Jun - 12 Aug	11 Oct - 28 Nov
Jyothi - Jyothi	04 Jun - 08 Jul	15 Sep - 19 Oct	11 Jun - 24 Jun	22 Sep - 10 Oct	28 May - 08 Jul	08 Sep - 19 Oct	28 May - 17 Jun	08 Sep - 28 Sep	21 May - 29 Jul	01 Sep - 09 Nov	18 Jun - 29 Jul	29 Sep - 09 Nov	18 Jun - 29 Jul	29 Sep - 09 Nov	25 Jun - 29 Jul	06 Oct - 09 Nov
Jyothi - Uma	04 Jun - 08 Jul	15 Sep - 18 Nov	11 Jun - 24 Jun	22 Sep - 18 Nov	28 May - 08 Jul	08 Sep - 18 Nov	28 May - 17 Jun	08 Sep - 18 Nov	21 May - 05 Aug	01 Sep - 16 Nov	18 Jun - 05 Aug	29 Sep - 16 Nov	18 Jun - 05 Aug	29 Sep - 16 Nov	25 Jun - 05 Aug	06 Oct - 16 Nov
Jyothi - Prathyasha	04 Jun - 08 Jul	15 Sep - 02 Dec	11 Jun - 24 Jun	22 Sep - 02 Dec	28 May - 08 Jul	08 Sep - 02 Dec	28 May - 17 Jun	08 Sep - 02 Dec	21 May - 19 Aug	01 Sep - 30 Nov	18 Jun - 19 Aug	29 Sep - 30 Nov	18 Jun - 19 Aug	29 Sep - 30 Nov	25 Jun - 19 Aug	06 Oct - 30 Nov
Prathyasha -	04	07	11	14	28	31	28	31	21	24	18	21	18	21	25	28

Prathyasha	Jun - 08 Jul	Sep - 11 Oct	Jun - 24 Jun	Sep - 27 Sep	May - 08 Jul	Aug - 11 Oct	May - 17 Jun	Aug - 20 Sep	May - 29 Jul	Aug - 01 Nov	Jun - 29 Jul	Sep - 01 Nov	Jun - 29 Jul	Sep - 01 Nov	Jun - 29 Jul	Sep - 01 Nov
Prathyasha - Uma	04 Jun - 08 Jul	07 Sep - 18 Nov	11 Jun - 01 Jul	14 Sep - 18 Nov	28 May - 15 Jul	31 Aug - 18 Nov	28 May - 24 Jun	31 Aug - 18 Nov	21 May - 12 Aug	24 Aug - 15 Nov	18 Jun - 12 Jul	21 Sep - 15 Nov	18 Jun - 12 Jul	21 Sep - 15 Nov	25 Jun - 12 Aug	28 Sep - 15 Nov
Prathyasha - Jyothi	04 Jun - 15 Jul	07 Sep - 18 Nov	11 Jun - 01 Jul	14 Sep - 18 Nov	28 May - 15 Jul	31 Aug - 18 Nov	28 May - 24 Jun	31 Aug - 18 Nov	21 May - 19 Aug	24 Aug - 22 Nov	18 Jun - 19 Aug	21 Sep - 22 Nov	18 Jun - 19 Aug	21 Sep - 22 Nov	25 Jun - 19 Aug	28 Sep - 22 Nov

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APPENDIX V

Area of paddy cultivation in Palakkad district

AREA UNDER CROPS 2014-15

(Area in Ha)

Sl. No.	District	Paddy				Grains							Total Cereals/ Millets	Pulses							Total food grains
		Autumn	Winter	Summer	Total	Cholam/Jower (including cattle	Ragi/Finger Millet (Koovaraku)	Maize	Small Millet (Thina/Chama)	Wheat	Other grains	Total Grains		Cow pea (Perum Payar)	Black gram (Uzhunnu)	Horse gram (Muthira)	Green gram (Cherupayar)	Tur/Redgram	Other plants	Total	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Thiruvananthapuram	963	1064	66	2093							0	2093	2	14		26		23	65	2158
2	Kollam	374	952	1	1327							0	1327	60	5		4		5	74	1401
3	Pathanamthitta	35	473	2084	2592							0	2592	12						12	2604
4	Alappuzha	11073	4657	18685	34415							0	34415	8			48			56	34471
5	Kottayam	5059	2890	9346	17295							0	17295	15					84	99	17394
6	Idukki	89	575	33	697		2	2		1	2	7	704	73					200	273	977
7	Ernakulam	1330	2924	390	4644							0	4644	359			1			360	5004
8	Thrissur	2864	13236	8051	24151							0	24151					1		1	24152
9	Palakkad	37371	42846	2695	82912	173	77	64	27			341	83253	24	122	89	8	827		1070	84323
10	Malappuram	494	5968	1940	8402							0	8402	168					131	299	8701
11	Kozhikkode	62	1708	551	2321							0	2321	5			1			6	2327
12	Wayanad	0	8651	1039	9690			1				1	9691					648		648	10339
13	Kannur	2638	2306	11	4955							0	4555	182	240	10	65			497	5452
14	Kazaragode	1629	740	296	2665							0	2665	96	22	12	10		1	141	2806
State Total		**63981**	**88990**	**45188**	**198159**	**173**	**79**	**67**	**27**	**1**	**2**	**349**	**198508**	**1004**	**403**	**111**	**163**	**1476**	**444**	**3601**	**2021109**

Source: Directorate of Economics & Statistics, Dept. of Agriculture & Co-operation

(Table – 3 Contd.....)

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APPENDIX VI

Percentile contribution by the components of hourly operating costs for different types of transplanters

Types of transplanters		Annual Operating Hours										
		50	100	200	300	400	500	600	700	800	900	100
Yanmar Vp8D	% Fixed cost	71	67	60	55	50	46	43	40	37	35	33
	% Variable cost	29	33	40	45	50	54	57	60	63	65	67
	Fixed cost	5481	2740	1370	913	685	548	457	391	343	304	274
	Variable cost	2229	1345	903	755	682	637	608	587	571	559	549
	HOC	7709	4085	2273	1669	1367	1185	1065	978	914	863	823
Yanmar Vp6D	% Fixed cost	70	65	57	51	46	42	38	35	33	31	29
	% Variable cost	30	35	43	49	54	58	62	65	67	69	71
	Fixed cost	4805	2403	1201	801	601	481	400	343	300	267	240
	Variable cost	2065	1290	903	773	709	670	644	626	612	601	593
	HOC	6870	3693	2104	1574	1309	1151	1045	969	912	868	833
Kubota NSPU-68C	% Fixed cost	71	67	61	55	51	47	44	41	38	36	34
	% Variable cost	29	33	39	45	49	53	56	59	62	64	66
	Fixed cost	4340	2170	1085	723	543	434	362	310	271	241	217
	Variable cost	1750	1050	700	583	525	490	467	450	437	428	420
	HOC	6090	3220	1785	1307	1067	924	828	760	709	669	637

APPENDIX VII

Patternator readings for solid cone and flat fan nozzles

Solid cone nozzle				Flat fan nozzle			
Collector tube	Water level, cm	Collector tube	Water level, cm	Collector tube	Water level, cm	Collector tube	Water level, cm
L8	0	L6	0.0	L11	0	L11	0
L7	2.8	L5	7.9	L10	0	L10	2
L6	2.5	L4	12.3	L9	0	L9	8.3
L5	8.5	L3	13.1	L8	3	L8	7.7
L4	13	L2	14.3	L7	8.5	L7	6.3
L3	11	L1	15.0	L6	6.9	L6	6
L2	11.6	R1	12.8	L5	5.5	L5	7.4
L1	11.8	R2	12.3	L4	5.8	L4	8.7
R1	9.8	R3	11.8	L3	6.4	L3	9.3
R2	11.6	R4	4.9	L2	8.2	L2	9
R3	12.2	R5	0.0	L1	8.8	L1	10.6
R4	6.1	R6	0.0	R1	10.8	R1	11
R5	0.6			R2	12	R2	11
R6	0			R3	11	R3	9.4
R7	0			R4	7.9	R4	7
R8	0			R5	6.5	R5	7.2
				R6	5.5	R6	5.8
				R7	3	R7	2.8
				R8	3.2	R8	
				R9	5	R9	6.4
				R10	3.5	R10	4
				R11	0	R11	0

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APPENDIX VIII

Pre-harvest and post-harvest parameters considered

Treatment plot - 1									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	96	94	95	91	99	97	95	98	95.625
No. of hills m^{-2}	28	24	26	24	19	23	30	20	24.25
No. of tillers per hill	13	19	22	27	22	26	22	25	22
Productive tillers m^{-2}	286	254	236	271	289	297	254	278	270.625
Unproductive tillers m^{-2}	11	16	13	12	11	10	14	9	12
No. of panicles per hill	16	15	14	16	19	13	14	12	14.875
Grains per panicle	76	72	79	75	71	76	81	73	75.375
Paddy yield m^{-2}	588	502	702	636	576	686	758	622	633.75
100 grain weight	2.4	2.05	2.1	2.3	2.4	2.9	3.1	2.8	2.50625

Treatment plot - 2									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	91	86	94	89	89	86	91	95	90.125
No. of hills m^{-2}	14	18	15	17	20	19	14	17	16.75
No. of tillers per hill	18	14	20	17	23	30	32	19	21.625
Productive tillers m^{-2}	251	248	256	269	298	257	296	287	270.25
Unproductive tillers m^{-2}	17	14	10	12	11	16	9	13	12.75
No. of panicles per hill	13	15	16	12	18	17	11	13	14.375
Grains per panicle	72	71	72	75	78	70	79	73	73.75
Paddy yield m^{-2}	468	454	520	596	558	412	600	536	518
100 grain weight	2.01	2.29	2.34	2.59	2.38	2.02	3.1	2.25	2.3725

Treatment plot - 3									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	104	92	96	96	91	101	97	99	97
No. of hills m^{-2}	15	20	21	23	20	17	24	19	19.875
No. of tillers per hill	25	23	23	23	21	28	22	21	23.25
Productive tillers m^{-2}	298	274	233	243	271	276	244	299	267.25
Unproductive tillers m^{-2}	10	12	16	14	12	13	16	10	12.875
No. of panicles per hill	14	16	17	12	11	19	14	13	14.5
Grains per panicle	82	71	73	73	70	80	73	79	75.125
Paddy yield m^{-2}	692	636	442	492	542	587	489	621	562.625
100 grain weight	3.42	3.27	2.02	2.18	2.51	2.33	2.16	3.17	2.6325

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Treatment plot - 4									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	103	101	105	94	97	110	108	111	103.625
No. of hills m^{-2}	24	20	24	24	22	24	21	27	23.25
No. of tillers per hill	20	19	26	24	22	16	29	22	22.25
Productive tillers m^{-2}	279	269	273	271	240	292	241	268	266.625
Unproductive tillers m^{-2}	10	16	12	13	14	10	16	11	12.75
No. of panicles per hill	18	12	16	15	13	11	13	20	14.75
Grains per panicle	76	74	71	74	72	77	81	69	74.25
Paddy yield m^{-2}	566	540	634	620	494	593	728	576	593.875
100 grain weight	2.3	2.28	2.3	2.34	2.14	2.56	3.71	2.34	2.49625

Treatment plot - 5									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	118	116	106	98	103	106	89	91	103.375
No. of hills m^{-2}	21	25	25	23	24	24	23	21	23.25
No. of tillers per hill	21	19	23	22	27	19	20	21	21.5
Productive tillers m^{-2}	274	268	269	272	283	271	241	245	265.375
Unproductive tillers m^{-2}	11	13	14	13	10	12	16	15	13
No. of panicles per hill	15	17	16	18	12	17	12	13	15
Grains per panicle	75	69	72	76	77	74	71	69	72.875
Paddy yield m^{-2}	550	574	568	568	614	567	497	503	555.125
100 grain weight	2.4	2.3	2.6	2.4	2.6	2.4	2.3	2	2.375

Treatment plot - 6									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	103	118	101	91	111	89	108	106	103.375
No. of hills m^{-2}	27	21	21	25	24	25	22	23	23.5
No. of tillers per hill	20	21	19	22	21	22	29	19	21.625
Productive tillers m^{-2}	288	231	298	284	289	264	258	259	271.375
Unproductive tillers m^{-2}	12	14	13	14	11	14	16	14	13.5
No. of panicles per hill	15	12	17	16	18	17	17	11	15.375
Grains per panicle	77	69	74	77	72	70	69	64	71.5
Paddy yield m^{-2}	620	484	562	531	568	508	414	476	520.375
100 grain weight	2.7	2.16	2.3	2.38	2.5	2.08	2	2.15	2.28375

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Treatment plot - 7									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	95	98	94	91	97	99	92	94	95
No. of hills m^{-2}	26	21	26	19	24	22	25	23	23.25
No. of tillers per hill	22	15	20	21	22	26	31	19	22
Productive tillers m^{-2}	234	244	265	291	244	291	291	241	262.625
Unproductive tillers m^{-2}	13	17	11	13	17	13	9	11	13
No. of panicles per hill	14	12	12	17	13	19	11	14	14
Grains per panicle	74	78	70	76	75	74	78	73	74.75
Paddy yield m^{-2}	497	502	511	551	489	576	602	516	530.5
100 grain weight	2.1	2.25	2.26	2.38	2.26	2.7	3.1	2.34	2.42375

Treatment plot - 8									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	94	97	91	99	92	89	101	95	94.75
No. of hillsm^{-2}	21	25	19	27	22	23	28	22	23.375
No. of tillers per hill	20	21	14	23	25	12	26	20	20.125
Productive tillers m^{-2}	239	254	284	278	244	288	290	259	267
Unproductive tillers m^{-2}	16	17	13	14	12	13	11	10	13.25
No. of panicles per hill	13	12	14	10	10	14	15	13	12.625
Grains per panicle	74	74	69	73	77	72	76	73	73.5
Paddy yield m^{-2}	512	482	456	547	498	562	579	523	519.875
100 grain weight	2.08	2.2	2.3	2.56	2.19	2.5	2.7	2.5	2.37875

Check plot - 1									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	92	89	88	84	90	96	89	88	89.5
No. of hills m^{-2}	21	24	20	17	17	15	16	18	18.5
No. of tillers per hill	22	23	21	14	24	23	16	18	20.125
Productive tillers m^{-2}	279	264	254	253	256	288	279	274	268.375
Unproductive tillers m^{-2}	13	12	11	14	12	10	12	13	12.125
No. of panicles per hill	12	16	14	13	10	11	12	10	12.25
Grains per panicle	70	69	77	71	71	73	75	73	72.375
Paddy yield m^{-2}	510	506	616	568	556	558	514	509	542.125
100 grain weight	1.85	2.45	2.33	2.05	2.1	2.3	2.4	1.99	2.18375

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Check plot - 2									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	90	87	86	88	85	92	90	86	88
No. of hills m^{-2}	20	18	22	19	23	16	15	17	18.75
No. of tillers per hill	18	22	23	19	26	22	14	16	20
Productive tillers m^{-2}	281	279	301	265	248	263	241	265	267.875
Unproductive tillers m^{-2}	14	16	11	12	15	13	12	11	13
No. of panicles per hill	14	12	17	11	10	14	9	12	12.375
Grains per panicle	71	69	74	71	70	73	68	71	70.875
Paddy yield m^{-2}	509	498	599	511	498	523	468	534	517.5
100 grain weight	2.01	1.76	3.1	2.59	1.38	2.02	2.34	2.25	2.18125

Check plot - 3									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	92	88	85	89	96	99	89	90	91
No. of hills m^{-2}	21	16	18	22	24	23	19	18	20.125
No. of tillers per hill	24	22	16	18	21	16	19	23	19.875
Productive tillers m^{-2}	245	289	241	288	231	297	239	304	266.75
Unproductive tillers m^{-2}	15	14	16	10	11	13	11	12	12.75
No. of panicles per hill	13	12	10	14	11	13	16	18	13.375
Grains per panicle	70	71	69	73	64	73	68	77	70.625
Paddy yield m^{-2}	498	501	487	523	443	512	412	536	489
100 grain weight	1.87	2.3	2.12	2.59	1.38	2.2	2.25	2.35	2.1325

Check plot - 4									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	99	92	95	89	87	94	92	98	93.25
No. of hillsm^{-2}	20	17	23	22	23	24	22	21	21.5
No. of tillers per hill	17	18	24	23	21	23	22	24	21.5
Productive tillers m^{-2}	268	245	234	267	240	289	241	298	260.25
Unproductive tillers m^{-2}	14	12	11	13	10	15	11	13	12.375
No. of panicles per hill	13	17	15	11	12	16	13	11	13.5
Grains per panicle	72	70	74	73	77	80	76	69	73.875
Paddy yield m^{-2}	502	524	489	434	545	478	531	559	507.75
100 grain weight	1.9	2.1	1.87	1.79	1.82	2.5	2.22	2.9	2.1375

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Check plot - 5									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	101	98	92	88	91	95	94	98	94.625
No. of hills m^{-2}	25	22	18	23	21	22	25	21	22.125
No. of tillers per hill	25	22	21	19	17	24	22	23	21.625
Productive tillers m^{-2}	291	257	231	224	246	266	239	247	250.125
Unproductive tillers m^{-2}	17	13	10	15	13	12	16	12	13.5
No. of panicles per hill	18	14	12	11	16	12	13	10	13.25
Grains per panicle	80	73	75	69	73	71	72	69	72.75
Paddy yield m^{-2}	546	431	478	421	488	501	495	456	477
100 grain weight	2.4	1.9	1.91	1.69	1.88	2.2	2	2.2	2.0225

Check plot - 6									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	89	97	94	93	88	87	103	97	93.5
No. of hills m^{-2}	25	21	22	19	20	17	23	22	21.125
No. of tillers per hill	16	19	22	24	23	20	23	24	21.375
Productive tillers m^{-2}	239	251	246	267	221	231	279	261	249.375
Unproductive tillers m^{-2}	13	11	12	14	10	15	13	12	12.5
No. of panicles per hill	11	17	14	13	12	14	12	13	13.25
Grains per panicle	69	72	75	72	75	68	76	71	72.25
Paddy yield m^{-2}	439	503	483	487	463	421	542	509	480.875
100 grain weight	1.7	2.32	1.66	1.8	1.9	2.1	2.34	2	1.9775

Check plot - 7									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	87	89	91	94	89	96	92	94	91.5
No. of hills m^{-2}	21	18	24	22	24	23	24	22	22.25
No. of tillers per hill	16	18	21	24	18	22	27	23	21.125
Productive tillers m^{-2}	187	196	243	265	214	281	246	251	235.375
Unproductive tillersm^{-2}	16	17	12	12	15	14	10	12	13.5
No. of panicles per hill	12	14	17	15	12	18	13	14	14.375
Grains per panicle	67	69	74	77	73	72	71	73	72
Paddy yield m^{-2}	487	493	511	567	487	567	582	471	520.625
100 grain weight	1.8	1.8	2.1	2.3	1.7	2.25	2.7	2.3	2.11875

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Check plot - 8									
No. of observations	1	2	3	4	5	6	7	8	Average
Plant height, cm	90	94	88	86	82	96	91	89	89.5
No. of hills m^{-2}	24	24	22	23	18	23	20	21	21.875
No. of tillers per hill	20	21	18	19	22	23	26	21	21.25
Productive tillers m^{-2}	234	229	213	224	233	249	252	231	233.125
Unproductive tillers m^{-2}	13	14	17	15	13	13	10	14	13.625
No. of panicles per hill	15	16	12	11	11	17	14	13	13.625
Grains per panicle	73	76	71	69	66	76	72	74	72.125
Paddy yield m^{-2}	498	516	503	487	436	571	488	457	494.5
100 grain weight	1.6	1.9	2	1.5	1.8	2.3	2.1	2.23	1.92875

APPENDIX IX

Table a. Paired t-test for plant height

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	97.85938	91.359375
Variance	56.31324	19.440228
Observations	64	64
Pearson Correlation	0.506235	
Hypothesized Mean Difference	0	
df	63	
t Stat	7.999624	
P(T<=t) one-tail	1.79E-11	
t Critical one-tail	1.669402	
P(T<=t) two-tail	3.57E-11	
t Critical two-tail	1.998341	

Table b. Paired t-test for number of hills per m^2

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	22.1875	20.78125
Variance	11.9325397	7.475198413
Observations	64	64
Pearson Correlation	0.04810909	
Hypothesized Mean Difference	0	
df	63	
t Stat	2.615642	
P(T<=t) one-tail	0.00556614	
t Critical one-tail	1.66940222	
P(T<=t) two-tail	0.01113228	
t Critical two-tail	1.99834052	

Table c. Paired t-test for number of tillers per hill

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	21.796875	20.859375
Variance	16.98983135	9.392609127
Observations	64	64
Pearson Correlation	-0.022401519	
Hypothesized Mean Difference	0	
df	63	
t Stat	1.444756538	
P(T<=t) one-tail	0.076740931	
t Critical one-tail	1.669402222	
P(T<=t) two-tail	0.153481863	
t Critical two-tail	1.998340522	

Table d. Paired t-test for productive tillers m^{-2}

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	267.6406	253.90625
Variance	403.7894	639.00694
Observations	64	64
Pearson Correlation	0.251077	
Hypothesized Mean Difference	0	
df	63	
t Stat	3.914825	
P(T<=t) one-tail	0.000112	
t Critical one-tail	1.669402	
P(T<=t) two-tail	0.000225	
t Critical two-tail	1.998341	

Table e. Paired t-test for unproductive tillers m^{-2}

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	12.890625	12.921875
Variance	5.11483135	3.628720238
Observations	64	64
Pearson Correlation	0.18588961	
Hypothesized Mean Difference	0	
Df	63	
t Stat	-0.09354793	
P(T<=t) one-tail	0.46288257	
t Critical one-tail	1.66940222	
P(T<=t) two-tail	0.92576515	
t Critical two-tail	1.99834052	

Table f. Paired t-test for number of panicles per hill

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	14.4375	13.25
Variance	6.281746032	5.206349206
Observations	64	64
Pearson Correlation	-0.069389319	
Hypothesized Mean Difference	0	
df	63	
t Stat	2.710775482	
P(T<=t) one-tail	0.004319504	
t Critical one-tail	1.669402222	
P(T<=t) two-tail	0.008639007	
t Critical two-tail	1.998340522	

Table g. Paired t-test for grains per panicle

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	73.89063	72.109375
Variance	12.51166	10.067212
Observations	64	64
Pearson Correlation	0.1411	
Hypothesized Mean Difference	0	
df	63	
t Stat	3.23432	
P(T<=t) one-tail	0.000972	
t Critical one-tail	1.669402	
P(T<=t) two-tail	0.001943	
t Critical two-tail	1.998341	

Table h. Paired t-test for paddy yield m^{-2}

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	554.265625	503.671875
Variance	5151.975942	1904.192212
Observations	64	64
Pearson Correlation	0.181783944	
Hypothesized Mean Difference	0	
df	63	
t Stat	5.261634457	
P(T<=t) one-tail	9.11932E-07	
t Critical one-tail	1.669402222	
P(T<=t) two-tail	1.82386E-06	
t Critical two-tail	1.998340522	

Table i. Paired t-test for 100 grain weight

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.43359375	2.0853125
Variance	0.13080434	0.1109142
Observations	64	64
Pearson Correlation	0.151954497	
Hypothesized Mean Difference	0	
df	63	
t Stat	6.152103364	
P(T<=t) one-tail	2.92065E-08	
t Critical one-tail	1.669402222	
P(T<=t) two-tail	5.84129E-08	
t Critical two-tail	1.998340522	

DEVELOPMENT OF ATTACHMENTS FOR FOUR-WHEEL RIDING TYPE RICE TRANSPLANTER

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Rice is the most important cereal food crop of the world providing major source of the food energy for more than half of the human population. Manual transplanting of paddy is being replaced by machine transplanting due to the drudgery and increased labour cost of the former. Four wheel riding type transplanters are getting popular as they can ensure speedy operation. These costly machines require an agro-economic analysis for their proper management. Another handicap in the use of these machines is that they need to be transported in another vehicle even to nearby areas, which results in increased cost of operation. The development of a suitable transport wheel system is also needed to reduce the cost of hire charges spent for transportation. The application of bio fungicides like pseudomonas and the foliar application of micro-nutrients on the mat nursery loaded in the seedling tray of these four-wheel transplanters will be a boon to farmers as this can reduce the labour cost simultaneously boosting the yield. Hence the development of an applicator attachment for spraying liquid formulations of bio-fungicides and micronutrients on the mat nursery loaded in the seedling tray of the machine, immediately before transplanting was also attempted.

Economic parameters of three types of four-wheel riding type rice transplanters, viz. Yanmar Vp8D (TR_1), Yanmar Vp6D (TR_2) and Kubota NSPU-68C (TR_3) were estimated considering the agronomic requirements of common rice varieties *Uma, Jyothi* and *Prathyasha.* For developing transport wheel system, 6-row Kubota make transplanter was selected. The wheel hub assembly was fabricated according to the design considerations. An electrically operated applicator attachment suitable for all makes of 6-row four wheel riding type transplanters were developed and successfully field tested.

From the agro economic analysis, it was found that the annual fixed cost, annual variable cost and hourly operational cost were maximum for TR_1, followed by TR_2 and the TR_3 respectively. The Unit Area Operating Cost (UAOC) was dependent on hourly operational costs and field capacities of the machines. TR_1 had the highest field capacity (0.4 ha h^{-1}) followed by TR_2 (0.38 ha h^{-1}) and TR_3

(0.33 ha h^{-1}). TR_1 had more UAOC than that of TR_2 and TR_3 up to the Annual Operating Hours (AOH) of 395 h. At 395 h UAOC of both TR_1 and TR_2 were equal. Beyond 395 h TR_2 had the maximum cost of operation among the three machines. Manual transplanting by labour contract required a cost of Rs. 10000 per ha and using these transplanters is economical than manual transplanting whenever the AOH is more than 102 h.

The pneumatic wheels of 680 mm diameter and width of 100 mm were selected for front wheel. The front wheel has wheel track of 1.29 m. For rear wheel it has diameter of 720 mm and 130 mm width. The rear wheel track was 1.37 m. The maximum and minimum speeds possible using these wheels are 1.14 to 9.88 km h^{-1}.

The applicator attachment had a 12 V electrically operated diaphragm pump, LDPE pipes as conduit, five solid cone nozzles fitted on a LDPE boom. The pressure developed by the pump was 620 kPa with a discharge of 1.89 l min^{-1}. The nozzles were selected based on the patternator studies. Five nozzles were placed at an equal distance of 35 cm on the boom of 1.8 m, with a spray span overlap of 14 cm. The droplet size was measured using bromide photo papers with pigmented spray solution and IMAGE-J image analyzing computer software. The droplet size at 50 cm height was in the range of 200 - 300 microns.

The field studies on effect of pseudomonas fluorescence application revealed the enhanced growth of rice plants. No fungal attack was observed in the plots which were treated with pseudomonas. The plants subjected to application of 'Sampoorna- KAU mutimix' had increased plant height, more number of tillers per unit area, more productive tillers, more number of grains per panicle, higher paddy yield and increased grain weight.